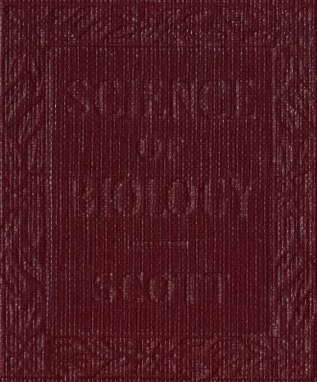

SCIENCE
OF
BIOLOGY

SCOTT

THE SCIENCE OF BIOLOGY

REVISED EDITION

A handbook for use in classroom work with
"The Science of Biology."

LABORATORY MANUAL
OF GENERAL BIOLOGY

THOMAS Y. CROWELL COMPANY
NEW YORK

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THE SCIENCE OF BIOLOGY

An Introductory Study

BY

ilmore
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OF THE CITY OF NEW YORK

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PREFACE

Any satisfactory introduction to the study of Biology should include a review of both plant and animal life; after which the general problems can be studied with greater interest and profit. This, in brief, is the general plan of the present book, and the reason for its arrangement.

After an introductory chapter we take up, in Part I, the biology of plants; followed in Part II, by the biology of animals. In each case the phyla are considered in the theoretical order of evolution so far as possible, and since this natural order is from the simple to the complex or from the generalized to the specialized, the student should make progress without difficulty. Biological principles and theories are introduced with each phylum, and reviewed later if illustrated by other groups. For example, parasitism is emphasized in the study of Sporozoa, Platyhelminthes, and Nemathelminthes. In the case of plant and animal phyla, the characteristic features of most groups are stressed by a study of type forms.

Part III, the largest of the three, considers in a progressive and orderly fashion many of the more important biologic problems, with illustrations drawn largely from Vertebrates, which of all creatures are nearest kin to man. The author still maintains that these general problems can be more satisfactorily appreciated after the approach presented in the preceding sections. The general plan of the former book thus remains the same, except that Part III has been considerably enlarged. The chapter on the Cell has been moved over to introduce this Part; and the consideration of Protoplasm is also included here, because protoplasm does not exist apart from cells, and cell and protoplasm should be closely associated in the mind of the student. Other chapters have also been modified.

Old figures throughout have been omitted or replaced by new ones, and many others have been added. A new feature for the illustrations is the direct labelling of each figure, making its interpretation easier.

The author has deleted, added to, rewritten and revised his earlier text, shortening some chapters and lengthening others, reflecting the needs of the class room since the work first appeared; nevertheless the present revision, he confesses, is not necessarily final since this is a changing world. However, he expresses the hope that the present biological offspring indicates growth since the days of its infancy.

He desires to thank again the various friends who kindly reviewed the text of the first edition. As regards the second edition, he wishes first of all to thank his colleagues, Ralph Kamenoff, Victor Schechter, Alexander Chaikelis, Herbert Johnson and Professors Herbert Ruckes, Earl Martin and Bertram Butler, for reading particular chapters; Carl Hoar, of Williams College, for careful review of Part I; R. A. Budington, of Oberlin College, for a critical review of Part II; Randolph Halsey, of Long Island University and Professor Ann Morgan, of Mt. Holyoke College, for reviewing Part III; Ernest Scott, of Columbia University, for reading the chapter on Physiology; Phebe Scott for continued helpful suggestions; and to the publishers who have made this revision possible. Credit is given in the text to those publishers and other authorities, who have courteously given permission to reprint figures from their publications.

Again this book is dedicated to the student who may find it of assistance in developing an interest in Biology; possibly aiding him to make further excursions in this field, and leading him to a better understanding of his own place in nature, and especially to a clearer conception of the biological foundations of that social organization in which he must "play the game" all the days of his life.

G. G. S.

New York
April, 1930.

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INTRODUCTORY

"The blue sky, the brown soil beneath, the grass, the trees, the animals, the wind, and rain, and stars are never strange to me; for I am in and of and am one with them; and my flesh and the soil are one, and the heat in my blood and in the sunshine are one, and the winds and the tempests and my passions are one."

—W. H. HUDSON, in "Hampshire Days."

CHAPTER I

THE BIOLOGICAL SCIENCES

Biology (from Greek = " life discourse ") is the science of living things. It includes the study of plants and animals; and in a broad sense, it embraces all knowledge concerning phenomena in any way related to life. However, it is usually restricted to narrower limits. Botany (fr. Gr. = " plant ") is that branch of biology that deals with plants, and Zoology (fr. Gr. = " animal discourse ") deals with animals.

Morphology (fr. Gr. = " form discourse ") is a branch of biological science that treats of the form, parts and structure of plants and animals. The field is so large that it would be very difficult to be an expert in both Plant Morphology and Animal Morphology.

Physiology (fr. Gr. = " nature discourse ") has to do with the study of the living processes that constitute life. It investigates functions of living things, the operations of the parts and the totality of activities which constitute life.

As biological sciences progressed, the investigation field widened to such an extent that gradually researchers confined their work to problems of more limited scope, and subsidiary sciences were formed. Many of these are chiefly morphological in character. Examples follow.

Anatomy (fr. Gr. = " to cut up "). Biologists call living things organisms. The word literally means that which is composed of organs. An organ is a part having a particular function. The heart pumps blood, and lungs are concerned in carrying oxygen to the blood. The heart and lungs are organs. Many living things, however, are small and simple and are able to perform all the functions of life without such organs as liver, heart, lungs or intestines. Even such small forms are considered organisms.

We obtain a knowledge of the organ composition of animals by dissecting with scalpel, scissors, needles and forceps. Dissection is a process of analysis. There is a *Plant Anatomy* as well as

Animal Anatomy. To write a book on the anatomy of any animal, one would dissect a great many specimens, make exact drawings of the entire animal and all the organs, determine the structural and functional relations of all the parts, and write accurate descriptions. The individual animals are by no means identical in structure, so that such an account would be an average picture. *Human Anatomy* is the science of the structure of the organs of the human body. The veterinarian must be familiar with the *Anatomy* of *Domestic Animals.* The anatomist may extend his studies to representatives of all kinds of animals and compare their organs and systems of organs. He discovers that all the forms possess a few general characteristics in common; that they may be subdivided into groups, each of which possesses the general characteristics common to all, and that each differs from the other in more specific peculiarities. Thus fishes, reptiles and birds have characteristics in common, and although there are many kinds of fishes yet *they* have common characteristics which distinguish them from reptiles or birds. The study of such resemblances of structure constitutes the science of *Comparative Anatomy.*

Histology (fr. Gr. = "tissue discourse"). One might dissect all of the organs of an animal and thus find that they are built up of a few different kinds of materials or tissues. They possess membranes covering the body, or lining cavities or tubes in the body. These membranes constitute a tissue called *epithelium.* Movements are brought about by the action of a tissue called *muscle;* parts are held together by *connective* tissues such as tendons; *nerve* tissues convey impulses from one part to another, integrating the activities of the organs; the parts are nourished by a tissue called *blood.* The science of the tissue construction of organs is called *Histology.*

Cytology (fr. Gr. = "hollow vessel-discourse"). A further analysis of tissues, by special technical methods, reveals the fact that all are made up of microscopic elementary units called cells, which vary greatly in form and function, and yet agree in fundamental respects. The study of cell morphology and physiology is *Cytology.*

Embryology (fr. Gr. = "embryo-discourse"). Most animals begin life as an individual cell. This divides and subdivides, forming more cells, at first similar in form but later different; then tissues are laid down and organs appear, until at last the adult stage develops. The science of the development of the individual is *Embryology.*

Pathology (fr. Gr. = "disease-discourse"). Organisms become diseased; organs and tissues are no longer normal, as in health. The study of the morphology and physiology of diseased tissues or organs, and comparison of these with the normal condition, constitutes the science of *Pathology.*

Palaeontology (fr. Gr. = "old existing things-discourse"). The earth has existed for thousands of centuries but life has not always been present on it. Many plants and animals existed in past geologic ages and perished. But some parts of their bodies have persisted as *fossils,* and from these certain scientists can reconstruct the morphology and physiology of the organisms of long ago. The science of organic life of past geologic ages is called *Palaeontology.*

Taxonomy (fr. Gr. = "arrangement-law"). The orderly arrangement of phenomena is a fundamental characteristic of science. Some biologists find that, due to natural relationships, plants and animals can be *classified* or arranged in groups and subdivisions. They have also ascertained a group of principles according to which this can be most satisfactorily accomplished. This is the science of *Taxonomy.*

Ecology (fr. Gr. = "house-discourse"). Plants and animals live in a world of constantly changing physical and chemical conditions. They are adjusted also to an organic environment made up of the plants and animals about them. Every organism must make successful adjustments in order to live. A study of the relation of living things to their organic and inorganic environment is called *Ecology.*

Genetics (fr. Gr. = "to be born"). A child is said to resemble in some respects its father, mother or other ancestors. He is said *to inherit* the blue eyes of his mother, for example. Phenomena of *heredity* are true not only of men but of plants and animals generally. The science which investigates the phenomena of heredity and endeavors to find the laws according to which similarities and differences appear in *closely related* organisms is called *Genetics.* It is one of the more recent biologic sciences.

Geographical Distribution. The animal life of a region constitutes its fauna, and the plant life its flora. The fauna and flora of a region are quite distinctive. Deserts have their own peculiar fauna and flora, very different from those of more productive regions. Tropical and temperate zones each have their characteristic plant and animal life. Moreover, similar regions, separated from each other by barriers, differ in respect to some of the animal and plant inhabitants on the two sides of the barrier. The study of the distribution of organisms in space is known as *Geographical Distribution.*

Evolution. There is a multiplicity of facts to prove that many contemporary varieties of plants and animals were not represented in the ancient life of the past. Seed plants appear to be of more recent origin than ferns, and dogs and cats are not as old as reptiles; fishes appeared before frogs, and reptiles before birds. The evidences gathered from various sources indicate that there has been a gradual *evolving* of living forms during geological history; that from primitive, simply organized plants and animals there have developed, along many lines, beings that are more specialized; from the apparently simple has been derived the relatively complex, but all are fundamentally related. This concept is known as the *Theory* of *Organic Evolution.* It is a scientific generalization, not based on guess or surmise, but is the work of many thoughtful and critical seekers after truth. If, at any time, new discoveries in biologic science discredit it, the theory will no longer form part of the body of biologic law.

The word *evolution* is from the Latin meaning "an unrolling," which does not literally express the biologist's conception. Someone has suggested that the word *phylogeny*, meaning "the development of races," be substituted for the word *evolution.*

Physiological Aspects. The above sciences are more or less morphological, but structures cannot be interpreted without considering their functional activity. Indeed, the conclusion that *function determines structure* is well founded. The anatomist does not completely understand an organ until he knows how it works. The most important things to know about cells are their physiological activities. How does a diseased organ function? Compare it with the working of a healthy organ. What is the effect on the activity of the organism as a whole? Lifeless organisms cannot adapt themselves to external changes. One might conclude that the palaeontologist is interested in morphology alone. But fossilized jaws and teeth indicate the kind of food eaten and suggest the fauna and flora, and therefore the climate of bygone ages. The palaeontologist endeavors to recreate the *living* world of long ago.

There is a great multitude of plant and animal species, all differing more or less widely from each other and yet all are organisms manifesting the phenomena of life. In spite of the many variations in morphological organization, all plants and animals must perform certain similar functions in order to live. The variety of these functions is limited and most of them are common to all living things. This is one of the reasons why it is possible to establish the general science of Biology. Morphological characteristics common to all living things play a part also in the construction of this general science.

In recent years the idea has steadily gained ground that to *understand* biological processes, *i.e.*, *life*, it is necessary to use the technic of physics and chemistry in the investigation of living things. There is an ever increasing extension of the concepts of physics and chemistry to cell phenomena. *Biophysics* and *Biochemistry* are important biologic sciences today.

Special Branches. The field of investigation is so great that investigators confine their researches to limited portions of the whole science and are thus enabled to master the particular part in which they are most interested. Some of these special fields of inquiry have been given special names. Thus, the Ornithologist studies birds; the Entomologist, insects; the Herpetologist, reptiles; the Ichthyologist, fishes; the Protozoologist, single-celled animals; the Bacteriologist, bacteria; the Neurologist, the nervous system. In medicine alone there are many special branches.

Related Branches. Many sciences are to a great extent biological in nature. Human and Animal Psychology, the study of mental phenomena, involve physiology. Anthropology is the biological study of man. It includes Ethnology, which deals more particularly with the origin, distribution and physical, mental and cultural differences between the *races* of *men*. Sociology, another anthropological science, is concerned with a study of the problems arising from the endeavor of men to *live in groups*. These problems are created by the struggle men must make to satisfy individual physiological needs. Economics has as its aim the discovery of the laws governing the origin, distribution and use of things needed to satisfy human desires which exist only because of human physiological activities. Language plays an important rôle in the existence of social organizations of men. The biologic nature of language is evident when one realizes that language is connected with commercial transactions, so necessary for the continued life of the members of the community.

Importance of the Study. Constant reference is made in the following pages to the relation between biology and human affairs. Biologic science illuminates so many problems of life, that a cultural education is incomplete without the experience of training in this field. Indeed, every man is aided in the *conquest* of *his world* by that understanding of nature which biology alone develops.

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PART I

THE BIOLOGY OF PLANTS

CHAPTER II

PHYLUM — THALLOPHYTA

Introduction. In most cases there is little difficulty in deciding whether a particular living thing is plant or animal. One of the obvious differences is the animation, or movement of animals, in contrast to the more passive state of plants. Both plants and animals, however, are fundamentally similar. If this were not true, there could be no general science of biology.

In order to discuss general biological principles, we must know something about the kinds of plants and animals and we must proceed with our study in a systematic, orderly fashion, which is one of the first rules of any science. The forms and functions of *Plants* will be our first study.

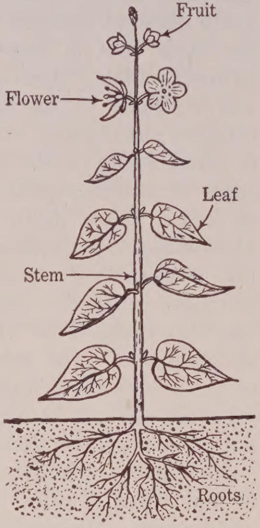


FIG. 1. — Diagram illustrating the organs of a complex plant.

Parts of a Complex Plant. Plants differ in complexity. Fig. 1 is a *diagram* of a complex plant. It has different *organs* — *i.e.*, (*a*) leaves; (*b*) stem; (*c*) roots; (*d*) flowers; and (*e*) fruit, with its seeds. The organs in turn are made up of more specialized structures called *tissues*. Fig. 2 is a diagram of the *tissues* of one of these organs, *i.e.*, a leaf. The microscopical study of tissues reveals the fact that they are made up of very small units called *cells*. A cell is a biological unit, and it has both structure and function. The cell wall and sap of the plant cell shown in Fig. 3 are non-living matter. The shaded portion is living matter or *protoplasm*. The oval-shaped body at one side is the *nucleus*, which differs chemically from the *cy-*

toplasm or the remainder of the protoplasm of the cell. A tree is a composite of thousands and thousands of cells. Bessey estimated that a single leaf of the size of an apple leaf contained at least 50,000,000 cells. The total number of cells in an entire apple tree is incomprehensible to the human mind.

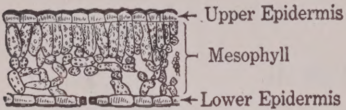


FIG. 2. — Diagram of tissues of leaf.

It is also a remarkable fact that these millions or billions of cells constituting the apple tree are all descendants of one original fertilized egg cell.

Single-Celled Plants. But there are plants which consist of single cells only, and yet are complete organisms. This implies that they carry on all the processes essential to life. They do many different kinds of things, as does the apple tree, in order to live. We naturally think of them as simple plants and we think of the apple tree as a complex sort of plant. Our comparison is based chiefly on the apparent differences in morphological complexity or of form. If we study the functional phenomena of a single-celled plant, we find it exceedingly complex. In fact, the most exhaustive studies yet made have not revealed the whole story of what goes on in one of these simple plants. The same statement can be made concerning *any* of the cells of the complex apple tree. It is safe to say that the scientific attitude in regard to this question is, that what we do not know is greater than what we do know.

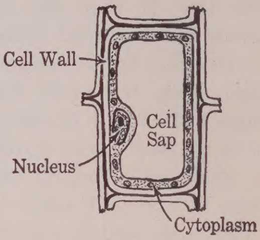


FIG. 3. — Diagram of a plant cell.

Some plant organisms consist of a single cell and others consist of multitudes of cells, which are organized into different tissues and organs. Many plants are within these two extremes of cell organization and vary in degree of complexity between the lowest single-celled types and the highest types, represented by the apple tree.

Four Phyla of Plants. At least a quarter of a million specific kinds of plants are known. It is manifestly impossible for most persons to become acquainted with every one of them. The *taxonomist,* however, finds that there are only four chief types of organization, and it is easy to become familiar with the characteristics of these and some of their subdivisions. It often gives pleasure to be able to assign plants to their proper morphological *group* even though one may not know the *species*. A species is a particular kind of animal or plant. The four groups or *phyla* into which the plant taxonomist divides the plant world are: 1st, *Thallophyta;* 2nd, *Bryophyta;* 3rd, *Pteridophyta;* 4th, *Spermatophyta.*

PHYLUM — THALLOPHYTA

A free translation of this word is "leaf-like plants." It suggests that Thallophytes do not have different organs like the apple tree, but are more simply organized. Some are single cells, some are mere rows of cells, some form thin sheets of cells. Some, as the single-celled types, are exceedingly minute, while some multicellular kinds form a great mass of cells. On the whole they do not possess any rigid tissues by virtue of which they can grow high above the ground like the apple tree. Thallophytes usually live in the water or in wet places. There is little cell differentiation among them. They have the simplest type of plant organization, and are thought to be the oldest types of plants, *i.e.*, their ancestors appeared on the earth *many* centuries (see page 487) before such forms as the apple tree. One of the great generalizations of biologic science is that of evolution. Its application here indicates that the plant world began with simple forms which developed as time went on into more complex forms. We are prone to regard the more simple forms as lower, and the more complex as higher. It is probably more correct to say that there has been a slow modification of generalized forms into specialized forms. Classifications of plants and animals attempt to portray the course taken in this evolutionary process. Classifications indicate relationships, and taxonomists determine these relationships by anatomical, histological, embryological and physiological studies of the forms. Taxonomists consider any sort of information that has a bearing on their problems.

From one point of view, Thallophytes are divided into two groups, *Algae* and *Fungi*. The Algae possess that unique pigment, chlorophyll, the green coloring matter of green plants, which is so vitally important to all life on this earth. Plants that possess chlorophyll can, in the presence of sunlight, make sugar and starch out of carbon dioxide and water. The Algae can do this. They possess this form of physiological *independence.* The Fungi, on the other hand, possess no chlorophyll and are thus physiologically *dependent.* They get their nourishment from dead organic matter, in which case they are *saprophytic;* or they are nourished on the tissues of living organisms, in which case they are *parasitic.*

Sub-Phylum I — Algae

Most Algae live in water or damp places. There are four groups according to their color: (*a*) *Cyanophyceae;* (*b*) *Chlorophyceae;* (*c*) *Phaeophyceae;* (*d*) *Rhodophyceae;* or stated more simply, the Blue-Greens, Greens, Browns and Reds, respectively.

Class 1. Cyanophyceae. These are single-celled forms or linear arrangements of cells, forming simple colonies. They have a blue-green color due to the presence of blue and yellow pigments in addition to the green. There are other combinations of pigments, and as a result some of these Algae appear to be orange or pink. The Red Sea derives its name from the color of certain Cyanophyceae which occur there in great numbers. Investigators do not agree as to the existence of a distinct nucleus. Some types form mucilaginous masses in which the cells are imbedded. Some types float on water in hot springs, while others grow on wet earth or stones. Single-celled forms reproduce by *fission, i.e.,* the cell divides into two cells, each of which grows to the size of the parent cell. If the form is filamentous, the filament increases in length by the division of some of its cells and the subsequent growth and division of their daughter cells. Longer filaments break, forming shorter ones, which again increase in length as indicated.

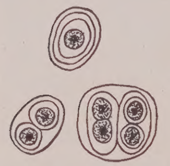


Fig. 4. — Gleocapsa.

Three forms are here described. (*a*) *Gleocapsa* (Fig. 4) is a single cell with a wall which forms a mucilaginous coating. When such a cell divides, each daughter cell wall becomes mucilaginous and is retained within the mucilaginous envelope developed by the mother cell, to form a simple colony. Gleocapsa is a blue-green, jelly-like mass found on damp walls and rocks. Its method of reproduction is called *simple fission.* (*b*) *Nostoc* (Fig. 5) is a linear arrangement of cells resembling a chain of beads, coiled up within a jelly-like envelope. At intervals a larger and clearer cell, the *heterocyst*, occurs. Segments between heterocysts may work their way out of the mucilaginous envelope and start new colonies. Usually little gelatinous colonies break away from the main colony. Nostoc is found in slimy masses floating on water or on damp soil. If the habitat becomes dry or cold, certain cells in the filament increase in size, storing food reserves, and the wall becomes thicker. Such cells resist destruction during unfavorable periods and on the return of better conditions have the power of forming new filaments. In this form we note three types of cells: 1st, vegetative cells; 2nd, heterocysts; 3rd, resting cells. (*c*) *Oscillatoria* (Fig. 6) is one of the most common forms. It is filamentous, with a very thin jelly-like envelope about the filament. The cells are short cylinders or discs. The filaments have a swaying movement; hence the name of the plant. The end cell where the movement is greatest is rounded.

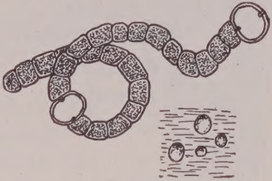


FIG. 5. — Nostoc. Two heterocysts are indicated in this filament. Four colonies at lower right.

Any cell in the filament may divide into two cells. Often gelatinous discs are formed at intervals. The longer filaments break at these points and the pieces grow again by division of cells, and by later growth of the daughter cells. This method of reproduction is *vegetative*.

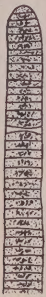


FIG. 6. — Oscillatoria.

The Blue-green Algae are often called *Fission Algae* because their method of reproduction is by a simple form of cell division, called fission. In some types, certain cells may grow to be larger than usual. Such cells, isolated from the filament, form new filaments. These special cells are called *spores*. A similar process is found among the Bacteria. The spores just indicated are not motile. Some of these Blue-greens become established in municipal reservoirs, imparting to the water a bad taste and odor.

Class 2. Chlorophyceae, or Green Algae. These are the common Algae of fresh water. There is no other pigment associated with the chlorophyll which occurs in bodies called *chromatophores*. The nucleus is well defined, and the plant body is very simple. The methods of reproduction are not specialized, except in a few cases. Existing Green Algae are considered to be similar to the ancestral forms from which the higher or more specialized plant groups have developed by evolution. Four forms are considered here.

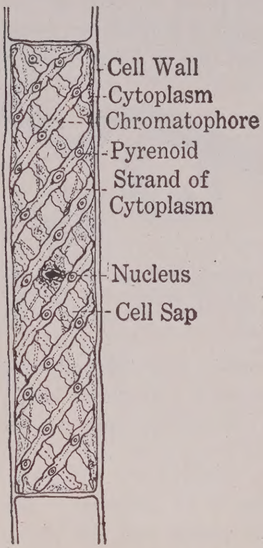

Cell Wall
Cytoplasm
Chromatophore
Pyrenoid
Strand of Cytoplasm
Nucleus
Cell Sap

FIG. 7. — Diagram of a cell of Spirogyra.

(1) *Spirogyra* (Fig. 7), sometimes called pond scum, occurs as masses of filaments floating in fresh water. The plant body is a long, slender filament consisting of cylindrical cells. Just inside the cell wall is one or more spirally wound green chromatophores with irregular edges, and at intervals in the chromatophores are small bodies called *pyrenoids* or starch formers. Around them small granules of starch are found. In the center of the cell space is the *nucleus* surrounded by a small amount of *cytoplasm*. From this central mass, strands of *cytoplasm* extend out to the periphery to a thin layer of cytoplasm lining the cell wall. The remaining space is filled with cell sap. The wall is composed of cellulose. Reproduction is peculiar. (*a*) Any cell may divide and make the filament longer. This is vegetative reproduction. (*b*) When two filaments lie side by side, two adjacent cells coming in contact may develop small tubes (Fig. 8) which form a canal connecting one cell with the other. The entire contents of one cell pass across through this canal to the protoplasm of the other cell and fusion takes place, forming a special cell with a thick wall. Studies indicate that the *chloroplast* of the motile cell disintegrates and that the *spiral chromatophore* of the fused cell is derived from that of the passive

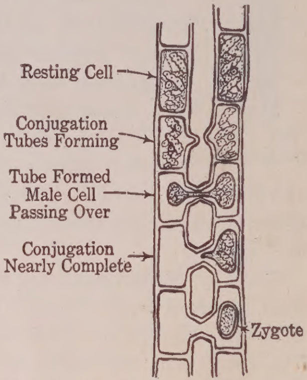

Resting Cell
Conjugation Tubes Forming
Tube Formed Male Cell Passing Over
Conjugation Nearly Complete
Zygote

FIG. 8. — Conjugation in Spirogyra.

cell. Specimens are found in which nearly all the cells of one filament have passed over into opposite cells of the other filament. It is now believed that the cells *moving across* are *male*, while the *stationary* cells are *female*. The two cells which unite are called *gametes* and the single fused cell is a *zygote*. In this condition, the winter or some other unfavorable period is passed. When conditions are right, the original walls decay, and each of the zygotes develops eventually into a new filament. It should be noted that such new filaments began life as a single cell formed by the *fusion* of two cells. Spirogyra is excellent laboratory material for obtaining a knowledge of the characteristics of plant cells.

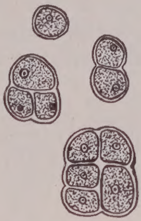


FIG. 9. — Pleurococcus. One cell, two cell, three cell, and five cell groups.

(2) *Pleurococcus* (Fig. 9), is morphologically simpler than Spirogyra. You may have observed a green coating on the shaded side of trunks of trees. A study of a minute portion of this green material reveals the fact that it consists of a great many very small green-colored cells. Each cell has a nucleus and a chlorophyll body. The cells divide and the daughter cells remain in association with the other cells. Possibly they secure mutual protection. Although apparently simple cells, each performs all the necessary functions of life, such as digestion, circulation, excretion, oxidation and photosynthesis.

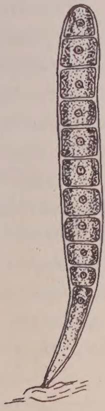


FIG. 10. — Ulothrix. Holdfast indicated at lower end of filament.

(3) *Ulothrix* (Fig. 10) is a filamentous form, consisting of short cylindrical cells, each with a nucleus and chromatophore. The basal cell acts as a holdfast to the substratum. This Green Alga has three methods of reproduction: (*a*) Vegetative. (*b*) Internal division of one cell into a number of cells. Each of these is called a spore. This method, called *Sporulation*, is employed by all the higher groups of plants. In the case of Ulothrix, each spore (Fig. 11), when liberated, has four motile processes, or *flagella*, which are organs of locomotion and by which the spores swim actively about for a time, settle to the bottom and by cell division form a new filament. Such actively swimming spores are

known as *zoospores*. There is a distinct advantage in this type of reproduction, because some spores may lodge in a new place, more favorable for successful development. (*c*) Any cell of the filament except the holdfast may divide internally more times than in the formation of zoospores, and so form still smaller spore-like cells. When mature, these are discharged, possessing only two flagella. After swimming about, if these bi-flagellate cells settle to the bottom, they disintegrate because individually they do not possess the power of developing into a new plant. But some of the swimming cells *fuse in pairs* (*conjugate*) and form *zygospores*, which have four flagella. Later these settle to the bottom and produce active zoospores, which then develop into filaments. It has been suggested that the small bi-flagellate cells are small zoospores. They differ from the latter, however, in that they must *fuse in pairs* to continue functioning. In *conjugating* there is a chance that bi-flagellate forms from different filaments may unite, forming a new combination of protoplasm which may have a better chance of survival than the ordinary zoospores. The small bi-flagellate cells are called *gametes*, because they unite (marry) to produce a cell that will eventually grow into a new individual. Since the gametes are approximately equal in size, they are called *isogametes*. The single, four-flagellated cell formed by the fusion of two gametes is called a zygospore. A more general name is *zygote*. The type of reproduction just described may be considered a very primitive form of sexual reproduction.

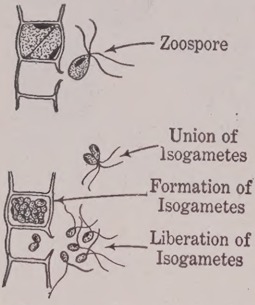


FIG. 11.—Reproduction in Ulothrix.

(4) *Oedogonium* is another filamentous Green Alga whose cells (Fig. 12) are cylindrical in form. Oedogonium reproduces in three ways also. (*a*) Vegetatively. This has already been defined. (*b*) Zoospores. These are produced by internal division of certain cells of the filament. The liberated spores are ovoid in shape with a crown of cilia near the smaller end. After swimming about they settle to the bottom and form new filaments. (*c*) Sexual Reproduction. Certain cells increase in size by storing up food, become spherical in shape and covered with a firm capsule. In-

side this capsule is a single large *egg cell, ovum, female gamete* or *megagamete.* All these words are synonyms. The ovum and its capsule form a body known as an *oogonium.* Other cells in the filament subdivide internally, forming very *small* ovoid cells, resembling the zoospores but much smaller. Each has a crown of cilia at its small end. These are *sperm cells, male gametes* or *microgametes.* The special body where they develop is an *antheridium.* The wall of the oogonium has a small perforation. The sperm cells (microgametes) escape from the antheridia and swim about actively among the filaments containing oogonia. Sperm penetrate the oogonia. Fertilization consists in the union of an egg nucleus with a sperm nucleus. The fused or conjugated sperm and egg (microgamete and megagamete) is a *zygote* or *fertilized egg.*

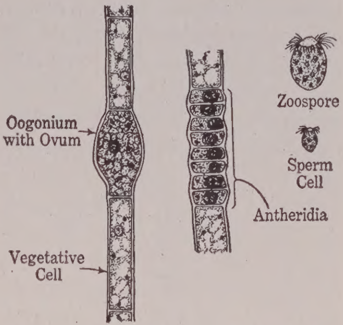


FIG. 12. — Oedogonium. Types of cells. (In part after Strasburger.)

The zygote germinates, *i.e.*, divides and grows, forming four zoospores, each of which produces a new Oedogonium filament (plant). The equal-sized gametes of Ulothrix were called *isogametes* in contrast with those of Oedogonium, which, being unequal or dissimilar are called *heterogametes.*

Reproduction involving the union of a microgamete and a megagamete to form a zygote is *sexual reproduction.* Oedogonium presents one of the simplest examples of sexual reproduction. At this point it is possible to state several generalizations of broad biological importance. It is evident that the setting apart of special cells for the production of eggs and sperm occurs in the simplest of plant forms, *i.e.*, sexual reproduction was established early in the evolution of plants. It is noted also that sex organs — even though simple — are organized before the appearance of special cells or organs for any of the other kinds of physiological processes. We will note these two generalizations in the animal world also. In the next place we find that eggs and sperm cells differ in important respects, while at the same time they agree in other just as important respects. Let us see what these are. Eggs are large, passive and filled with nutriment. Sperm are small, very active and possess a minimum of nutriment. Egg and sperm agree in the *quantity* of their *nuclear contents* although the nuclei are probably *qualitatively* different. The essential feature of fertilization consists in the fusion of the two nuclei. The entire mechanism suggests a scheme for bringing this about. In certain species of Oedogonium, oogonia and antheridia may occur on the same filament. Such species may be called *monoecious* or *hermaphrodite,* in which case the *individual* is double sexed. In other species, some filaments possess only antheridia and may be considered male. Others, that possess only oogonia, may be considered female. In this case, the species is *dioecious* or separate sexed. Oedogonium possesses a very simple plant body, but it is specialized in its reproductive mechanism. Ulothrix illustrates the transition from the simpler asexual method of reproduction toward the sexual method, which is clearly present in Oedogonium. *Sex organs* may be defined as structures specialized for the production of sex cells. The sex organs of Oedogonium are very simple, being merely specialized single cells. Sex organs are far more complicated in higher plants and animals. In addition there are also highly specialized accessory structures. Such elaborate systems are necessary to bring about the same result that is effected by the simple method we have studied in Oedogonium. The result in all cases of sexual reproduction is a conjugation of a male cell, or sperm, and that of a female cell, or egg. Reproduction by spores, which is asexual, means continuation of the same protoplasm, while sexual reproduction, because of the union of different cells, means the possible formation of a new combination of protoplasmic characteristics.

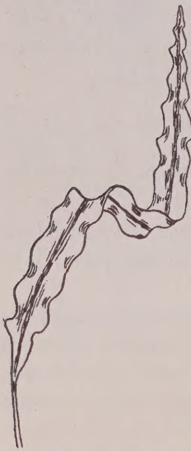


FIG. 13. — Laminaria — a kelp.

Class 3. Phaeophyceae. The Brown Algae are usually marine forms attached to rocks. A brown pigment gives the characteristic color which masks the green chlorophyll. Some of these forms are of great size, being about 150 feet in length. Along the Pacific Coast are great kelp beds (Fig. 13), many miles in extent. They are of great potential value because they contain potassium salts, an important ingredient of commercial fertilizers. It is said that one ton of dried kelp contains 500 pounds of these salts and three pounds of iodine, together with other valuable compounds. Phaeophyceae are very specialized Algae of uncertain origin. Chlorophyceae are comparatively small aggregations of cells, while the Phaeophyceae possess innumerable cells. Differentiation into special tissues is evident in the kelps. One form is described because it illustrates further specialization in the development of sex organs.

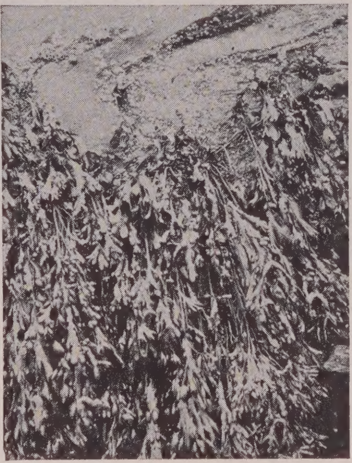


Fig. 14. — Fucus growing on rocks. Photographed at low tide. (Photo by Fread.)

Fucus or Rockweed (Fig. 14) lives as masses of short plants attached to rocks, where tidal waters cause it to be uncovered at low tide. It has strap-shaped branches (Fig. 15) which fork in twos or *dichotomously*. The branches possess air bladders which float the plant. Fucus produces no asexual spores, but always reproduces sexually. The ends of some branches have swollen tips or *receptacles*, covered with warty bodies. There is a small pore at the outer end of each of these small swollen bodies. This pore leads into a chamber (Fig. 16) called a *conceptacle*. Its walls are lined with a mass of hair-like filaments called *paraphyses*. Some species of Fucus are

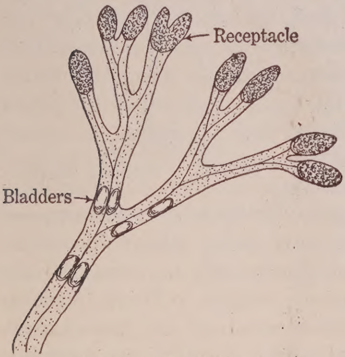


Fig. 15. — Fucus. Drawing indicates branching habit of plant body.

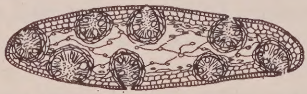


Fig. 16. — Section through receptacle of Fucus showing eight oogonial conceptacles.

monoecious, while others are *dioecious.* In either case the sex organs are located among the paraphyses of a conceptacle (Fig. 17). In the *monoecious* type, little club-shaped bodies or antheridia are attached to paraphyses. The antheridia produce many biciliated sperm. In the same conceptacle are found large spherical bodies attached to the wall by a short stalk. These are *Oogonia.* Each oogonium produces eight eggs, as a rule. The eggs and sperm are discharged and the active, swimming sperm swarm about the floating eggs and fertilize them. From this union a new plant develops. In the *dioecious* forms, the conceptacle contains only antheridia *or* only oogonia. It should be noted that the organs of reproduction are restricted to particular places in this form. Although Fucus does not reproduce by spores, yet some Brown Algae reproduce by spores as well as sex cells. Both are produced in special organs, the spores in *sporangia* and the sex cells in *gametangia.* The conceptacle of Fucus is a *gametangium.*

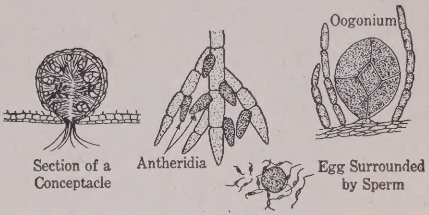


Fig. 17. — Reproduction in Fucus. From Sinnott's *Botany,* copyright by McGraw-Hill Book Co Reprinted by permission.

Class 4. Rhodophyceae. The Red Algae are the most specialized of the Algae, and have no apparent relationships with the other groups. They are mostly marine, not so large as the browns and occur most abundantly in warmer seas. A red pigment masks the green chlorophyll. Some types (*Corallines*) secrete lime, and such forms aid in the building of coral reefs. Rhodophyceae reproduce by spores, asexually, and also sexually by means of eggs and sperm, which occur in special organs. From *Chondrus crispus,* Irish Moss (Fig. 18) *gelatin* is obtained and from certain other types such as Gelidium, *agar-agar,* a gelatinous substance used extensively in bacteriology, as a culture medium for Bacte-

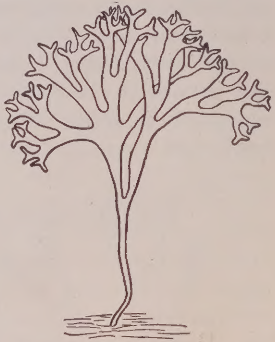


Fig. 18. — Chondrus crispus.

ria. In some species of Red Algae, the life history is cyclical. Certain individual plants produce only spores. These form plants which bear sex organs which produce sex cells. The fertilized egg or zygote forms a plant which produces only spores. In other words, a spore-producing plant develops from a fertilized egg, and a plant producing sex cells develops from a spore. The plant that produces spores is called a *Sporophyte*, while the plant that produces gametes (eggs and sperm) is called a *Gametophyte*. The Sporophyte generation alternates with the gametophyte generation. This is known as *Alternation of Generations*. It is characteristic of all the higher plant groups, and is one of the great features of plant phylogeny or race development.

Diatoms (Fig. 19) are unicellular Algae varying greatly in shape. They are bilaterally symmetrical. One of the two halves or valves overlaps the other like the lid of a box. They contain considerable silica. Their walls are marked with projections or depressions in regular patterns of many kinds. They reproduce by division, the two valves separating and each forming half of a new cell or plant. They not only occur in fresh water, but countless millions are found at certain seasons near the surface of the ocean, where, with other minute forms of plants and animals, they make up that vast world of microbiology called the *Plankton*. You have heard the statement that "All flesh is grass," because plants are the basic food of animals. That statement could be amplified, for fish is flesh and someone has said that "All fish is diatom." This is explained as follows. Some of our larger food fishes of the sea subsist on smaller fishes. These smaller fry eat other organisms which subsist on others which feed on plankton, of which diatoms may be the chief constituent. The siliceous "shells" of dead diatoms settle to the ocean floor, forming thick deposits during the ages. Due to changes in the earth's surface vast areas of what was once the floor of the sea become part of the dry land, and here

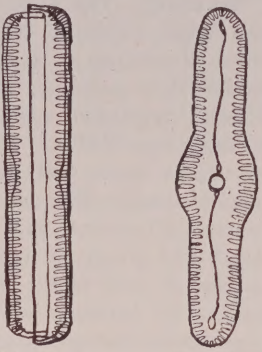

Side View Top View

FIG. 19. — Navicula — a diatom. From Smith and Others: *General Botany*, Revised Edition, copyright 1928 by The Macmillan Company. Reprinted by permission.

and there are found great deposits of siliceous or *diatomaceous earth.* Petroleum is also said to have been derived from diatoms. The surface markings of certain diatom valves are so fine that they serve as objects for the testing and standardization of microscopic lenses. The color of diatoms is due to chlorophyll and a yellowish brown pigment. Some taxonomists classify them with the Chlorophyceae and others with the Phaeophyceae. Diatomaceous earth is used as an abrasive medium in silver polish and tooth pastes.

Summary. The Algae range in form from single-celled plants and simple chains of cells to great masses of cells associated in three dimensions of space. Reproduction is at first by *simple fission,* then *vegetative,* then by *asexual spores* and by *gametes.* Fission, vegetative reproduction and sporulation are forms of asexual reproduction. The sexual method of reproduction, with sex organs, is also well established although the plant body seldom becomes highly differentiated. While alternation of generations (asexual alternating with the sexual) is not characteristic of the Algae as a group, yet it is represented. The Algae are the most ancient of true plants that have chlorophyll. Of all the four groups, the botanists are agreed that the Chlorophyceae must be regarded as that group which was ancestral to the next group of higher plants, known as the *Bryophytes.*

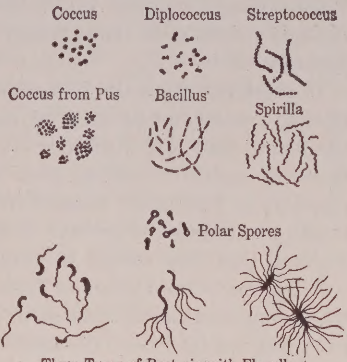
Sub-Phylum II — Fungi

Fungi are simple dependent plant forms that cannot make carbohydrates from carbon dioxide and water. They possess no chlorophyll and are either *parasitic* or *saprophytic.* They reproduce by cell division, by budding, by means of spores, and there is also an indication of the sexual method of reproduction in some cases.

Class 1. The Bacteria. Bacteria are here considered with those plants which do not possess chlorophyll and are *parasitic* or *saprophytic.* Some do not regard them as Fungi, because the word *fungus* literally means mushroom, and the plant body of the mushroom consists of a mass of filaments. Yet Bacteria are *sometimes* called *Schizomycetes,* which literally means Fission Fungi, because they reproduce by fission and because they often form *filamentous colonies,* and the plant body of true Fungi is a mass of filaments.

Indeed some bacteriologists regard Bacteria as comprising a group of organisms entirely distinct from plants and animals.

Bacteria are the very smallest known organisms. High powers of microscopic magnification are needed to make them visible, and even then, some which are known to exist because of their influence cannot even be seen. Three types as to form (Fig. 20) are: (1) the *Coccus*, which is a spherical cell. *Pneumococcus*, the organism which causes pneumonia, belongs to this general group. Cocci may be arranged in rows, in which case they are called *Streptococci*, as the organisms which cause septic sore throat, blood-poisoning and possibly tonsillitis. (2) The *Bacillus* is rod shaped. Bacillus subtilis, the Hay Bacillus, is a common form. (3) The *Spirillum* is shaped like a cockscrew, the number of revolutions varying from one to many. Organisms which cause cholera have this form. The student should not conclude that all Bacteria are disease-producing. Every person may take Bacteria into the body daily with food, drink or air. Even though some of these are potential disease makers they are actually harmless when we are *immune* to them. But there are many very useful Bacteria. Bacteria possess no organized nucleus, but it is believed that nuclear material is distributed throughout the protoplasm. Some have little protoplasmic motile processes, called flagella, by the movement of which they possess considerable power of locomotion. Some have a single flagellum at one end. Cholera Bacteria move in water at the rate of 15 mm. an hour. Bacteria reproduce by simple *fission*, *i.e.*, the bacterium divides in two and each daughter cell soon grows to a mature size and is then ready for division. So rapid is the reproduction at times that millions may be formed from one original cell in the course of a single day. Certain types are able to surround themselves with a sticky gelatinous matrix, forming a capsule which they secrete. Such a formation is known as *Zoogloea*, as "Mother of Vinegar." Under unfavor-



Three Types of Bacteria with Flagella

FIG. 20. — Types of Bacteria.

able conditions some Bacteria go into a resting stage called a *spore*, in which the organism is surrounded by a very thick wall. In this state the cells resist death from desiccation or other adverse conditions. When proper conditions return, the spore wall bursts and the living cell escapes, feeds and reproduces, thus recolonizing the medium in which it lives. Bacteria live practically everywhere, — in water, in deserts, in air, in soil, in hot springs, in ice, in milk and in the bodies of plants and animals. They concern civilized life to such an extent that the separate biological science of Bacteriology has come to be of the greatest importance.

In studying them the bacteriologist determines first their morphology, which is the smallest part of his task. He also studies the form, color and structure of their colonies, grown on various types of nutritive media, such as gelatin and agar-agar. The physical and chemical changes produced by these colonies on the media are important criteria of identification. Some species are so small that they cannot be studied microscopically.

After the Germ Theory of Disease had been accepted, of course many investigators attempted to discover the specific microorganisms causing infectious diseases. Bacteria were shown to be the causative agents in many cases. But no microorganisms were found in many others. It was suggested that in these cases the organism was so small it could not be seen microscopically and so could not be isolated. But, on the other hand, it might be present in infectious material from a diseased animal even though this substance were passed through a bacteria-proof filter. Frosch and Löffler in 1898 succeeded in *transmitting* foot and mouth disease with such a *filterable virus*. Today about forty filterable viruses are known. Among them are those of rabies, infantile paralysis, typhus fever, measles and smallpox. Whether the organisms are Bacteria or Protozoa is not known.

It is an almost universal characteristic of living things that they use atmospheric oxygen in their metabolic activities. There are Bacteria, however, that exist in the absence of atmospheric oxygen. These are known as *anaerobic* Bacteria, to distinguish them from the great majority of air-loving forms which are called *aerobic*. Special cultural methods are used for the cultivation of such forms. Indeed, anaerobic Bacteria perish if exposed to the atmosphere. Some kinds of Bacteria are *parasitic*, *i.e.*, they inhabit and obtain their food from living organisms. They are not always harmful. In the large *coecum* of the rabbit, cellulose, which is a large part of its diet, is digested by the resident Bacteria. On the other hand, in the human intestine, under certain conditions they cause excessive fermentation, produce distressing volumes of CO_2 and sufficient organic acids to irritate the mucous membrane of the intestine and cause diarrhea.

Cycle of the Elements. *Saprophytic* Bacteria live on dead organisms and play an important rôle in the cycle of organic life. By means of ferments or enzymes they break down, step by step, the complex proteins of the organism into simpler compounds of putrefaction, so evident by their offensive odors. They form ammonia. Carbohydrates and fats are disintegrated into carbon dioxide and water. The classes of Bacteria that bring about decay are of vital importance to the existence of plant and animal life. These Bacteria free chemical elements for further use in new generations of animals and plants. They have been called the traffic policemen of the elements, keeping these in circulation, now forming substance of living matter and later being part of the inorganic world to be organized still later into living tissues again. The carbon dioxide formed in processes of decay is returned to the atmosphere and may again be used by green plants in the manufacture of carbohydrates. A certain group of Bacteria, *Nitrosomonas,* converts the ammonia above referred to into nitrites. Some of these nitrifying Bacteria can even use carbon dioxide in the absence of chlorophyll.

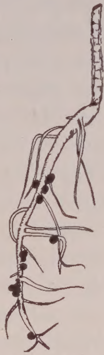


FIG. 21. — Tap root of a legume showing several nodules of nitrogen-fixing Bacteria.

Some biologists have speculated as to the earliest formation of living things in the comparatively early days of the Earth. They have suggested that Bacteria similar to Nitrosomonas might have been the first living things. *Nitrobacter* is a bacterium which can change nitrites into nitrates, and thus such salts as potassium and calcium nitrates may be formed which are taken up by roots and from such compounds, the nitrogen for plant proteins may be obtained. Certain nitrogen-fixing Bacteria (Fig. 21) live in nodules on roots. They are able to utilize the free nitrogen of the air and form compounds which are used by those plants with which the nitrogen-fixing Bacteria are associated. Other Bacteria decompose organic compounds containing sulphur, iron and phosphorus, and so bring about compounds of these elements which can be utilized by living plants.

Pathogenic Bacteria. — It is generally known that some Bacteria cause disease. They destroy tissues directly or secrete toxins or poisons which prevent normal physiological function. Pneumonia, typhoid fever, tuberculosis, diphtheria, cholera and bubonic plague are caused by pathogenic Bacteria.

Relationship. — The Bacteria resemble the Cyanophyceae in some respects. Reproduction in both groups is by fission. Both types of organisms produce a jelly-like matrix. In neither is there a well-defined nucleus. Some biologists, on account of these resemblances, group Bacteria and Cyanophyceae into the group *Schizophyta, i.e.*, plants that reproduce by fission. Some regard Bacteria as degenerate Blue-green Algae. However, Blue-green Algae possess chlorophyll, in spite of the fact that this is masked by a blue pigment, *phyocyanin.* The presence of chlorophyll makes it possible for these Algae to manufacture carbohydrates from carbon dioxide and water. This, the Bacteria, as a whole, cannot do. They must have already prepared carbohydrates to feed upon. In other respects, Bacteria resemble still other groups of organisms.

Class 2. Myxomycetes. This is a group of simple organisms of somewhat uncertain position, which are usually considered with plants. Some taxonomists, however, regard them as simple animals and call them *Mycetozoa.* The common name is *slime molds.* The organism consists of a mass of naked, slimy protoplasm which has a creeping motion. Tongue-like processes at one side are put forth and extend in a certain direction. The protoplasmic mass at the opposite side glides slowly in the direction of the movement. Slime molds live on decaying wood or dead leaves in dim, damp places. There is no chlorophyll present and they are therefore dependent. In the protoplasmic mass are found distributed nuclei. The entire mass is a colony of cells without cell walls. Such an association of cells without separating walls is called a *syncytium.* The slime mold feeds on Bacteria and other small organisms. It simply engulfs its food. At times the superficial protoplasm forms a hard external layer inclosing a thickened protoplasmic mass within. In this resting state it may remain for years but will resume its normal activity when proper external conditions return. The method of reproduction is more plant-like than animal-like. In this process very small, spherical, single-celled spores are formed. When the spores are mature, the sporangium, or spore case in which they were formed, becomes dry, bursts and the spore cells are discharged. From the spore a single irregular-shaped cell escapes. This cell develops a *flagellum.* It moves about and in this stage it resembles Protozoa or single-celled animals. It may divide by fission many times, producing many similar cells. At a later period the flagella disappear. Many such irregular-shaped cells come together. In this way a new protoplasmic mass, similar to the parent organism, is formed again. In food habits, Myxomycetes resemble animals. In the flagellated motile state, as well as in the single-celled ameboid stage, they are quite animal-like. But in the production of spores, they are like plants and especially like the Fungi. When one considers all the characteristics of simple forms like the Myxomycetes, one feels that, after all, it is quite difficult to decide as to just what an animal or plant is. When we think of plants and animals, we usually have in mind higher plants and higher animals, between which there are many apparent differences. Consideration of these lowly organisms, on the other hand, serves to emphasize the underlying unity of organic nature. The words *plant* and *animal* were *invented* many years ago before much was known concerning microorganisms. It is probable that many new puzzling organisms will be discovered. It may be necessary to establish a new category of living things.

Class 3. The Phycomycetes. The body of these plants is called a *mycelium.* The same name applies to the plant body of the next two groups. The mycelium is composed of a mass of filaments called *hyphae,* and it is connected with dead or living organisms by special absorbing root-like organs called *rhizoids.* Upright branches produce spores and so are called *sporophores.* The Phycomycetes resemble filamentous Algae that have lost their chlorophyll. There are no walls to separate the cells of the mycelium. Such an arrangement is a *syncytium.*

1. *Albugo* (Fig. 22) is a mold which grows in leaves or flowers of plants such as the mustard and radish. The mycelium grows into cell spaces of the host, forming a ramifying network. The spore-producing organs form clusters under the epidermis, separating this from the tissue underneath. Thus the epidermis becomes broken. Spores are formed one after the other by constrictions of the end of the sporophore. They form in rows. Spores pro-

duced in this way are called *conidia.* A leaf infected with sporophores presents the appearance of a white blister. The fungus is, therefore, commonly known as *white rust* or *blister blight.* The spores are scattered by wind. They germinate on the surface of wet leaves and form zoospores which move over the leaf, rest and send hyphae through the air pores in the epidermis of the leaf, thus infecting it. This form possesses sexual reproduction also. *Potato blight,* or *rot,* and *grape blight* are due to other closely related forms.

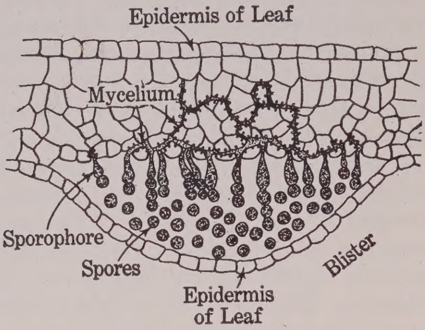

Epidermis of Leaf
Mycelium
Sporophore
Spores
Blister
Epidermis of Leaf

Fig. 22. — Albugo.

2. *Rhizopus* (Fig. 23) is the common black mold which grows on bread. Damp bread, kept under a glass jar, will exhibit a luxurious growth of black mold in a few days. The spores are in the air everywhere. The mycelium is a syncytium. The branching hyphae present a woolly appearance. Long vertical stalks, sporangiophores, end in round black sporangia, in which a great number of spores are produced. This black mold possesses a sexual method of reproduction also. Rhizopus is dioecious — *i.e.,* male and female mycelia occur. If two near-by hyphae of opposite sex occur near each other and touch, short side branches from each grow toward the other. The ends unite. The united part becomes separated from the two hyphae by cross partitions. This

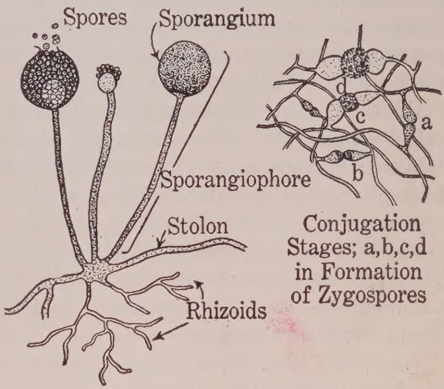

Spores
Sporangium
Sporangiophore
Stolon
Rhizoids
a
b
c
d
Conjugation Stages; a,b,c,d in Formation of Zygospores

Fig. 23. — Rhizopus.

cell is virtually a fusion of two cells, forming a zygote by the conjugation of the two gametes. The zygote develops a thick wall. After a time it germinates, forming a small mycelium, with a sporangiophore and sporangium.

The great famine in Ireland, in 1846–47, was caused by the destruction of the main food supply, the potato, by a Phycomycete, *Phytophthora infestans*. Our own federal government employs many inspectors to maintain a strict quarantine against the introduction of plant diseases from foreign countries. No sensible person can object to keeping out such undesirable immigrants. Moreover, each state is constantly on the watch to prevent the introduction within its borders of plant diseases that might enter in the course of interstate commerce.

The Phycomycetes resemble the Green Algae in the formation of oospores and zygospores.

Class 4. The Ascomycetes. Most of the Fungi belong to this group and the next. The mycelium consists of filaments in which the cells are separated from one another by walls. Sex organs are reduced or absent. The characteristic of this group is the possession of the *ascus* or sac in which the spores (ascospores) are produced.

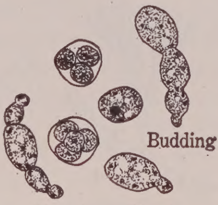


FIG. 24. — Yeast.

1. *Yeasts* (Fig. 24) are simple Ascomycetes. There are about forty varieties of these microscopic yeasts. The form used in bread making is called *Saccharomyces cervisiae*. It consists of ovoid-shaped, colorless cells with a nucleus and a sap cavity in the cytoplasm. The cells feed on sugar solution. The products of their metabolism are carbon dioxide and alcohol. The carbon dioxide "raises" bread dough. Yeast can reproduce by forming a bud. This remains attached to the parent cell and grows. The bud cell may also form a bud. Chains of yeast cells are thus formed. Yeast also forms spores. If food is scanty, the cell divides twice, forming a sac (ascus) with four spores. The wall is hard and resistent. Later, when favorable conditions return, the wall ruptures, releasing the spores. These are driven about by wind and may reach a favorable medium for further growth.

The yeast cell contains an enzyme, zymase, which changes a simple sugar, glucose, to carbon dioxide and alcohol. The formula is $C_6H_{12}O_6 = 2(CO_2) + 2(C_2H_5OH)$. It is a process of fermentation. Pasteur pointed out that the power was dependent on the ability of the yeast cell to secure energy for its life processes from disintegration of sugar and without the use of the oxygen in the air. Yeast is on this account anaerobic — it can live without air — *i.e.*, without free oxygen. The alcohol produced is the result of an incomplete oxidation. If the process were completed as in ordinary combustion, the end products would be CO_2 and H_2O. When the percentage of alcohol increases to about 15%, the fermentation ceases, due to the formation of such substances as succinic acid and glycerine. Yeast was used empirically for ages before it was really understood. About 1830 it was found to be a plant and the genus, Saccharomyces was established in 1839. The chemical processes involved in this case of fermentation were reported by Pasteur in 1861. In modern commercial bread making the greatest care is taken to use only pure cultures of a particular kind of yeast, and to avoid contamination with wild yeasts.

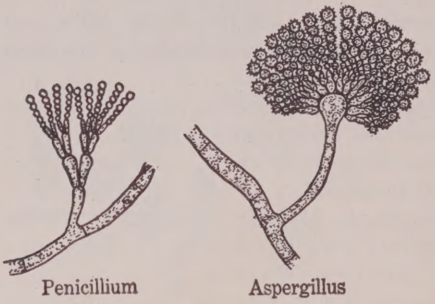

Penicillium Aspergillus

FIG. 25. — Penicillium and Aspergillus.

2. *Penicillium* (Fig. 25) is a Blue Mold. The mycelium grows on various substrata. The hyphae are septate, and possess an enzyme that can change bread to carbon dioxide and alcohol. Erect branches grow here and there and divide at the apex. The upper end of each terminal branch develops chains of spores. If grown where there is a poor supply of oxygen or none at all, certain short hyphae fuse and form a spherical body called an ascocarp. Within this, spore sacs or asci develop. Each ascus produces eight spores. In due time the spores are liberated and form new filaments. Penicillium produces a number of types of enzymes and so can digest many types of food, and this probably explains why it is so widespread. It imparts the green color and some of the flavor to Roquefort cheese. It is also present in other varieties of cheese (Stilton and Camembert). *Aspergillus* is another common form.

3. *Ergot* (Fig. 26) is a black substance that is produced by an Ascomycete, *Claviceps*, infecting rye. A head of rye may contain a number of such *ergotized* grains. Flour made from such grains is poisonous. Extract of ergot is a powerful drug used in medicine to contract blood vessels and so arrest hemorrhages.

4. *Chestnut blight* is another Ascomycete that appeared in New York about 1904. By 1911 it had destroyed about twenty-five million dollars worth of chestnut trees within a radius of two hundred miles of New York and since then has extended much further.

5. *Black knot* is a fungus disease attacking the branches of plum and cherry trees.

6. *Truffles* and the *Morel* are examples of edible Ascomycetes.

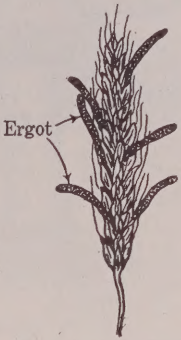


FIG. 26. — Head of rye infected with ergot.

7. The *Lichens* (Fig. 27) comprise a unique group. They are the familiar grayish dry growth on old fences, trees or rocks and are composed of an Ascomycete or Basidiomycete, in the mycelium of which live simple Green or Blue-green Algae. This association of two kinds of organisms is called *symbiosis*. Litmus, used to test the alkalinity or acidity of solutions, is derived from a lichen. Iceland moss, a lichen, is used as food by natives of northern countries. Reindeer Moss (Cladonia) grows on very poor soil in the far north and is eaten by reindeer. Lecanora, another lichen, grows in the deserts of northern Africa and is thought to be the "Manna" referred to in the Bible. From the lichen Rocella was obtained a purple dye once used in dyeing silks and woolens.

FIG. 27. — Lichen. (Photo by Schechter.)

Class 5. Basidiomycetes. Basidiomycetes are usually larger than Ascomycetes. The spore-producing organs are more prominent. The distinctive feature explaining the name is a special structure, the *basidium*, which produces basidiospores.

An example of a saprophytic form is the common edible mushroom, *Agaricus campestris* (Fig. 28), which grows in meadows under natural conditions, and is now a food product cultivated extensively in mushroom cellars and caves. It should not be called a toadstool — a name popularly given to somewhat similar forms which are inedible. The word *toadstool* is probably a popular derivation from the German words "Todt" and "Stuhl" meaning "death stool." The deadly *Amanita*, which is sometimes mistaken for Agaricus, is a true "todtstuhl."

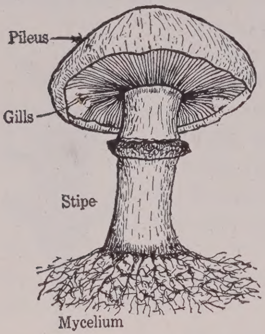


Fig. 28. — Agaricus.

Agaricus campestris has a short, upright stalk or *stipe*, at the upper end of which is the umbrella-like *pileus*. On the under surface of this are seen the radiating lamellae or *gills* (Fig. 29). The "mushroom" grows from a tangled *mycelium* in the earth. The stipe and pileus are composed of hyphae. The hyphae of the gills superficially merge into short, thick, club-shaped bodies, the *basidia* (Fig. 30). At the tip of each basidium are two or four small projections, at the end of which basidiospores are produced. Germinating *basidiospores* develop into mycelia which produce other "mushrooms."

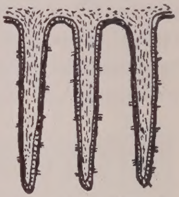


Fig. 29. — Gills of Agaricus.

There are hundreds of basidia, some old, some producing spores and some as yet immature. The spores are very light and can be carried long distances by air currents. It has been estimated that one mushroom can produce two billion spores. Bracket Fungi, found attached to trees, have a mycelium that ramifies into the trunk, destroying the living tissues. In some toadstools the underside of the pileus is toothed, in others it is porous. Puff balls (Fig. 31) are large, round, edible forms. It has

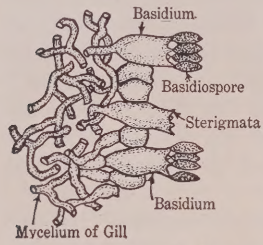


Fig. 30. — Reproductive organs on gill of mushroom. From Gager, *General Botany*, copyright 1926, P. Blackiston's Son & Co., reprinted by permission.

been estimated that one of the larger types may produce ten billion spores.

Gager states that there are over a thousand edible Fungi available. He also says that the only criterion of edibility is determined by experiment, *i.e.*, eat and find out. This, however, is not recommended, but it is suggested that the experienced mycologist be consulted.

Some of the most destructive plant diseases are produced by other Basidiomycetes. One of these, still unconquered, is wheat rust. During the years 1919 to 1923 it is said that this disease caused a loss of thirty million bushels of wheat. Stinking smut occasioned the loss of eighty million bushels of corn between the years 1917 and 1920. The white pine blister rust threatens the destruction of over a quarter billion dollars worth of pine trees. Some idea of the great economic loss caused by Basidiomycetes has been indicated above. One reason for making it difficult to eradicate these fungous diseases is that so many spores are produced. They are very light and are carried afar by air currents. They are very small and cannot be easily detected. They are also very resistant.

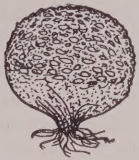


FIG. 31. — Puff ball.

Endothia, the Ascomycete which is the cause of chestnut blight, probably came from Japan, where the native chestnuts are practically immune to it. There are thousands of Fungi. De Bary in 1872 *estimated* 150,000 kinds. There are many whose life histories are not as yet completely known. Some recognized plant diseases are caused by certain forms of these Fungi Imperfecti.

Summary of Thallophytes

The plant body consists of single cells, filamentous arrangements of cells or cells in masses with little differentiation into tissues for special physiological functions. Morphological differentiation into tissues so characteristic of higher groups *begins* here. The principal method of reproduction is by means of spores. Contemporary Thallophytes are representative of the earliest plants to appear on the earth. The Algae are typically aquatic as were also probably the first plants. The Cyanophyceae are the simplest from the point of view of structure and reproduction. The Chlorophyceae, whose cells exhibit an organization similar to those of higher groups, are the simplest and more closely approximate the hypothetical ancestors of the Bryophytes. Among the Phaeophyceae are found the largest Thallophytes. The Rhodophyceae are the most specialized. They exhibit alternation of generations so characteristic of higher groups. The Fungi include a miscellaneous collection of dependent forms. While reproduction is chiefly by spores, yet sexual reproduction by isogametes and heterogametes is present in some forms. The Bacteria and Blue-green Algae are similar in many respects. The Phycomycetes are regarded as degenerate forms of a certain type of Green Algae. The relation of Ascomycetes and Basidiomycetes to the other Algae is not at all clear. It is thought that Basidiomycetes were derived from the Ascomycetes.

Apart from such theoretical considerations as to the origin and relationship of the various groups of the Thallophytes, the fact is that one should have an acquaintance with their biology on account of the vital ways in which they affect mankind. The Fungi and the Insects are probably the most formidable contenders with Man for dominance on this earth. The Algae are of some economic importance. Moreover the occurrence among them of single-celled forms, linear arrangements of cells, sheets of cells and masses of cells has an evolutionary significance. We also find the transition from reproduction by fission to that type involving an alternation between reproduction by spores and reproduction by gametes.

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CHAPTER III

PHYLUM — BRYOPHYTA

Introduction. The second *phylum* of plants is known as the Bryophyta. This word literally means "moss" plants. The mosses or Musci are, however, only *one* of *two* groups which form the Bryophytes. The other group is that of the liverworts or Hepaticae. These two groups differ markedly in their general appearance and structure, but their organs of reproduction and general life histories are so similar that both are included in the general term, Bryophytes.

Class I — Hepaticae

Marchantia (Fig. 32), a typical liverwort, is a little, flat, leaf-like plant, living in patches on damp soil or rocks near water. It is strap-shaped, with a distinct mid-rib, and the plant body forks at one end. This forking is brought about by a special type of growth at the tip and the plant dies away at the opposite end. After a time each of the branches will fork again, and the opposite end will die and separate the two branches which were originally united. In this way the plant spreads slowly over the ground, forming green areas. This method of extension is a *type* of *vegetative reproduction* which is not restricted to the liverworts, but is present in ferns and flowering plants.

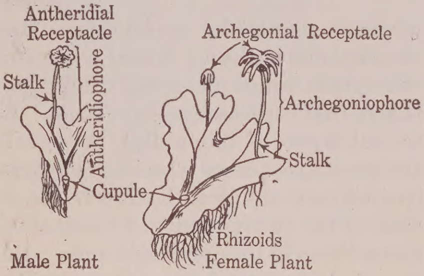

FIG. 32.— Marchantia.

Marchantia is a *liverwort,* which word literally means "liver plant." The liverworts have a lobed appearance and someone long ago fancied that the plant body resembled the lobes of the human liver. There used to be a medical philosophy known as the Doctrine of Signatures. According to this the medical properties of plants and other objects could be determined by certain signs. In this particular case it was thought that a decoction made from liverwort would be good medicine for the cure of liver disease. It was also used in the treatment of kidney and lung diseases, but there is no evidence that it was efficacious.

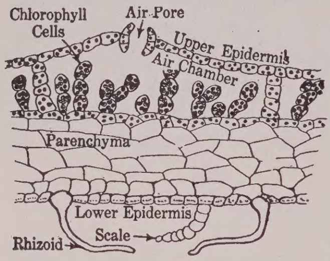

Fig. 33. — Marchantia. Vertical section through thallus.

Examination of a portion of a Marchantia *thallus* or plant body shows that it is green in color above, and underneath, it has many threadlike structures, to which earth adheres. If one examines the upper surface with a strong hand lens, many small pores are found, each in the center of a diamond-shaped area. A section (Fig. 33) through the thallus, studied microscopically, shows that the upper surface is composed of a single layer of protective cells, called the *upper epidermis*. Here and there are *air-pores*, guarded by special cells. These air pores open into *air chambers* and in the air chambers are strings of cells which contain *chloroplasts*, whose presence gives the green color to the thallus. It is here that carbohydrates are made. Below the air chambers are several layers of thin-walled, polygonal-shaped cells constituting the *parenchyma* tissue where carbohydrates are stored. The upper parenchyma cells form the floor of the air chambers, while the side walls of the air chambers are made of cells which extend from the parenchyma to the upper epidermis. Underneath the parenchyma is a single layer of *lower epidermal* cells which protect the parenchyma from the earth below. Both epidermal layers prevent loss of water from the cells by evaporation. *Scales*, which are very small, leaf-like, multicellular extensions, are found on the lower epidermis and there are also fine, thread-like *rhizoids*, which are long, slender, thin-walled cells which extend into the soil, absorbing soil fluids containing compounds from which will be made protoplasm for added plant growth. The new protoplasm is not made from these soil compounds alone, for the carbohydrates made by the chlorophyll cells are also necessary. The study of the plant body has revealed the fact that liverworts possess considerable *tissue differentiation.*

Marchantia has a unique method of asexual reproduction. Small cup-like organs called *cupules* (Fig. 32) grow on the upper surface. In these cupules are produced tiny leaf-like structures called *gemmae.* They are miniature vegetative organs. When mature, they become dislodged and are shed from the mother thallus. They may be scattered by the wind to a new area, which if favorable will be the site where a new growth of Marchantia becomes established. Many of course fall on " barren ground."

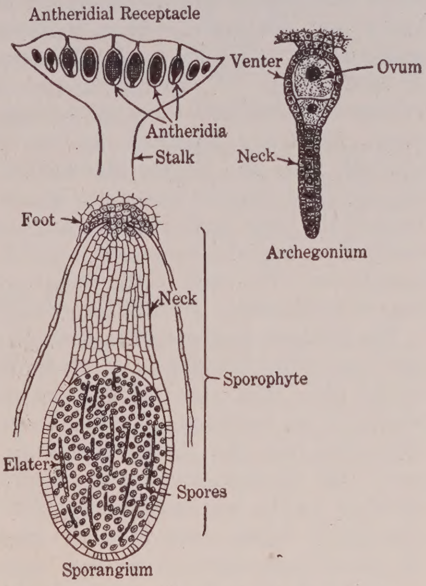

Fig. 34. — Antheridia, archegonium, and sphorophyte of Marchantia.

There are also elaborate sex organs, borne on separate plants, and so Marchantia is *dioecious.* These sex organs in some respects are similar but also show important differences. Arising from the mid-line of a male thallus is one or more long stalks, each with a disc-like structure at its upper end. The entire organ is an *antheridiophore* (Fig. 32) composed of the stalk and an upper disc, the *antheridial receptacle.* A study of a cross-section of the antheridial receptacle (Fig. 34) reveals a number of organs, the *antheridia.* Those near the center of the disc are larger and more mature. Within the antheridium are rows of cells which produce antherozoids, sperm or *male gametes, i.e.,* small bi-ciliated cells which swim actively about in water.

The female sex organs arise from female thalli and are called *archegoniophores.* Each consists (Fig. 32) of a stalk, at the upper end of which is an inverted disc, the *archegonial receptacle,* with several finger-like projections. On the under side of this are the *archegonia* (Fig. 34), small flask-shaped organs, each with a neck and a globular base or *venter* consisting of one layer of cells. Within the neck is a row of neck-canal cells; the lower cell inside the venter is a single *ovum* or *female gamete.* The whole archegonium is on the under surface of the receptacle and the neck is directed downward. When the plants are sexually mature and when the water conditions are favorable for sperm locomotion, as during a heavy rain, the sperm, swimming about, arrive near the archegonial necks. The neck-canal cells have degenerated, thus forming an open passage. A single sperm works its way down one of these archegonial neck-canals and its nucleus unites with that of the ovum, forming a fertilized egg or zygote. The green, independent, male and female Marchantia plants are *Gametophytes* because they produce gametes. The word *independent* is used, because the plant makes its own protoplasm and supplies its own energy from organic compounds, which it has made from inorganic ingredients. The stalk of the female archegoniophore is short at time of fertilization, but later grows longer.

The fertilized egg or zygote develops a small but many-celled structure which remains attached to the archegonial receptacle at the place where the fertilization took place, namely, in the venter of an archegonium. This many-celled structure is the *Sporophyte* (Fig. 34). It is about 1 mm. in length, and has three parts: (*a*) the foot, a group of cells by which the sporophyte is attached to the archegonial receptacle and through which the sporophyte obtains food from the parent gametophyte thallus; (*b*) the neck or short, thick stalk connecting the foot with the (*c*) terminal spore case or *sporangium.* The spore case is a thin-walled capsule within which many small *spores* are produced. Along with these are small spirally-twisted cells called *elaters.* When the spores are mature, the spore case splits open. The twisting movements of the elaters, which occur as a result of changes in the moisture content of the air, aid in the scattering of the spores, which is also favored by the elongated stalk of the archegoniophore. Once free of the plant, air currents may carry the spores far from the plant which produced them. Each spore is a single cell which is capable of growing into a new Marchantia thallus. The differences between the gametophyte and sporophyte should be noted. The gametophyte is large, green, independent and long-lived, while in comparison the sporophyte is small, without chlorophyll, dependent on the gametophyte and short-lived. Nevertheless the sporophyte is an essential generation interpolated between two successive gametophyte generations. Further reference to this will be made in our study of the moss, the fern and the seed plant.

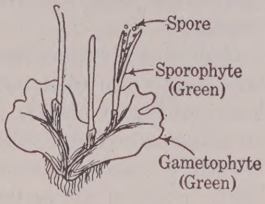

Fig. 35. — Anthoceros.

Anthoceros (Fig. 35) is a liverwort which possesses a long, stalk-like, *green sporophyte*, extending upward from the flat thallus. Cells in the wall of *this* sporophyte contain chlorophyll, with the result that the sporophyte has a certain degree of independence of the gametophyte thallus. True breathing pores are present and there is a special tissue, *meristem*, which provides for continued growth of the sporophyte. It lacks only roots to become independent.

Class II — Musci

The true mosses are more specialized Bryophytes. A true moss is a *land plant*, although it inhabits damp and shady places. A " piece of moss " can be easily separated into many very small plants, each with a central upright stem, from which radiate still smaller green " leaves." The lower end of the stem is buried in the earth. Thus, the mosses are distinctly different from the prostrate thallus-like liverworts.

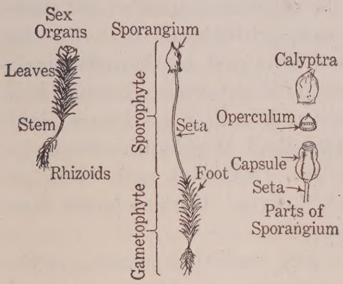

Fig. 36. — Polytrichum. At left, a gametophyte; middle, gametophyte with sporophyte; right, parts of sporangium.

Polytrichum (Fig. 36) is a genus with relatively large plants and hence more convenient for study. It has a number of common names such as robin's-wheat moss, pigeon's-wheat moss and hair-cap moss. A microscopic study of a cross-section of the slender upright stem (Fig. 37) demonstrates a surface layer of *epidermal* cells which contain chloroplasts, also a central region where there are somewhat elongated cells which serve for the *conduction* of fluids from the root-like structures in the earth to the " leaves," and vice-versa from the "leaves" to the rest of the plant. Between the central cells and the peripheral epidermis are polygonal-shaped, thin-walled cells, constituting the *parenchyma,* used for food storage.

Radiating out from the stem (Fig. 36) are many small leaf-like organs, green in color but more simple in structure than the true leaves of higher plants. They consist as a rule of but one layer of polygonal-shaped cells, containing chlorophyll. Here, sugar (starch) is made from water and carbon dioxide with the aid of sunlight. Some of the surface cells of the underground portion of the stem have long, thread-like, thin-walled extensions called *rhizoids.* These are filamentous lines of cells with oblique cross walls. The rhizoids may branch and form an underground network of threads. They not only assist in anchoring the plant but also absorb the mineral compounds in the soil water, so important for the manufacture of new protoplasm.

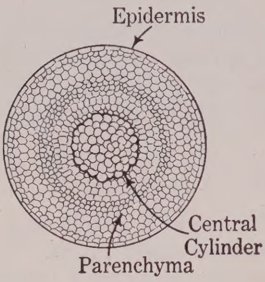

FIG. 37.—Polytrichum. Cross-section of stem.

The amount of leaf surface determines the amount of starch (and eventually new protoplasm) that can be made. The amount of starch manufactured by Marchantia is directly proportionate to the ground area it occupies because it is a prostrate thallus. On the other hand, each Polytrichum plant occupies a much smaller ground area than Marchantia, yet has a much greater starch-producing surface. Although each " leaf " is small, yet the total area of all the " leaves " is much larger than the ground area occupied by the plant.

The Polytrichum plant, we have just studied, is a *gametophyte.* *Gametes* are produced in special sex organs, as in Marchantia, and they resemble those of Marchantia. Some moss plants are monoecious, others dioecious. Polytrichum and Marchantia are dioecious, *i.e.,* some plants are male and others female. The sex organs are borne at the tips of the plant (Fig. 36) among modified leaves. The whole structure has been wrongly styled a " moss flower." It is *not* a *flower.* At the tip of a male plant (Fig. 38), in among the modified leaves, are a number of long, thin-walled sacs, or antheridia, in which are formed *sperm*, long, coiled, bi-ciliated cells. The antheridia are free and not buried in tissue as in Marchantia. The archegonia (Fig. 38) are free, also, and resemble somewhat those of Marchantia. Incidentally, they are examples of the largest archegonia formed during the evolution of plants, and they also possess more cells. Each archegonium consists of a neck and venter inside which is a single *egg*. When eggs and sperm are mature and the water conditions are favorable, the bi-ciliate sperm swim about, and if one comes near to an *archegonium* it works its way down the neck, and the nucleus of the sperm unites with the nucleus of the egg, forming a zygote. From the zygote, a *sporophyte* (Fig. 36) gradually develops.

This is not the minute structure that we found in Marchantia. It possesses the same three parts, however: (*a*) a *foot*, which is an elongated mass of cells located in the upper end of the gametophyte stem, having grown down through the archegonial venter into the stem; (*b*) from the foot there extends *up into the air*, a long, slender, brown stalk or *seta*, a few inches in length; (*c*) at the upper end of the seta is a large capsule or *sporangium* (Fig. 36), which consists of a box-like structure with a lid, called an *operculum*, surmounted by a cap called the *calyptra*. The calyptra and operculum may fall off, and the spores still be retained by the *peristome*, an internal border of teeth. In damp weather the teeth spread over the spores, preventing escape. In dry weather the teeth bend out and the spores escape.

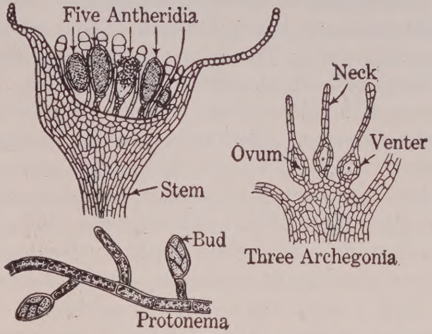

FIG. 38. — Polytrichum. Upper left, tip of male plant; right, tip of female plant; lower left, protonema.

Each spore is the germ of a new *gametophyte generation*. Undoubtedly many spores fall on "barren ground" and do not develop. When shed from the spore case, they are probably carried away by air currents. The elevation of the sporangium favors distribution by air currents.

If conditions are favorable, they develop into a branching, filamentous network (Fig. 38) of long cells with oblique cross walls. This plant body is called a *protonema*. Its resemblance to filamentous Green Algae is at once evident. Certain branches of the protonema grow along the surface, others grow into the soil. The latter lose their chlorophyll and become rhizoids. Any green cell of the surface filaments may form a bud from which an upright moss plant will grow, with stem and leaves. The protonema is distinctly part of the gametophyte generation. It may continue to progress along the ground, forming buds and new aerial plants. This is a type of vegetative reproduction comparable to that described in the case of Marchantia.

Sphagnum is a moss which grows in swampy or wet places. The gametophyte has a branching stem to which are attached very small leaves. The leaves have some cells which have no protoplasm but can absorb and retain water. Between them are small cells with chloroplasts. A mass of dried sphagnum absorbs water like a sponge. The best kinds will take up fifteen to twenty times their weight in water. Sphagnum was widely used as a surgical dressing in the Russo-Japanese war, and to a considerable extent in the World War. Nurserymen pack plants for shipment in sphagnum. In certain localities there are beds of it which have been growing for centuries. New growths form on top of the old. Thus, a peat bog is formed. Peat cut out in blocks and dried makes excellent fuel. The surface plants are literally lineal descendants of ancestors whose dead remains are directly under them.

Summary. A comparison of the gametophyte with the sporophyte generation shows resemblances to the liverwort life history. The green plant which we call a moss is a gametophyte, just as the liverwort is a gametophyte. Both produce sex organs, antheridia and archegonia, sperm and eggs. In each case the gametophyte is independent, *i.e.*, it has chlorophyll-bearing cells where starch can be manufactured from inorganic materials. In both liverwort and moss, the gametophyte is longer-lived than the sporophyte. The sporophyte is dependent on the gametophyte. The sexual generation alternates with the asexual. The asexual generation produces spores, no longer motile as in the Algae, but provided with a capsule rendering them proof against destruction by dessication. The spores are wind-driven and thus the species is distributed

Summary of the Bryophytes

Bryophytes are small forms. They live in a variety of habitats, such as cold, damp places where there is little sunlight or where the soil is poor. They have a wide distribution over the earth. They have left little, if any, fossil record in the rocks. They are descendants of plants which developed from the Green Algae. Liverworts are more primitive than mosses. The Musci represent the most *specialized* forms attained by the Bryophytes — standing *at the end* of a line of evolution which began with the liverworts.

Alternation of Generations is well established in the Bryophytes and is characteristic of all higher groups. Spores and gametes are produced in different plants. The gametophyte is the conspicuous, chlorophyll-bearing, starch-making stage. It has attained its highest development among the Bryophytes. In higher groups it is further and further reduced in size but does not lose its essential importance.

The Bryophytes represent the successful transition of plants from their original home in the water to life upon the land. It is interesting to note that the liverwort still remains near water. It has organs for absorbing water from the soil and thick-walled, upper epidermal cells which prevent too rapid loss of water from its tissues. It has special tissues for manufacture of starch. Why did not the Bryophytes become larger, more conspicuous or dominant? Let us consider this question. We think of a great oak tree as a successful type of plant. What are important features of such a successful product? There is a great stem exhibiting many branches above ground and we rightly think of the extensive root system. But after all, the essential feature of the entire stem system is the display of myriads of leaves presenting an enormous, thin, green layer to the sunlight, making possible the production of a proportionate amount of starch. Such a magnificent structure is impossible in the Bryophyte, for there the gametophyte is the starch-producing stage and also the gamete-producing stage. Gametes of Bryophytes require water for the completion of their function. This keeps the gametophyte *near* the ground — close enough to it so that rains at the right time of year will produce enough water to enable the sperm to swim to the eggs. The combination of producing starch and free-swimming gametes on the same plant restricts the size of the gametophyte. Polytrichum possibly represents the extreme extent to which a starch-making gametophyte could develop.

If the starch-making and starch-storage function could be transferred to a *green* sporophyte, which possessed the power of furnishing material for unlimited increase in cells, it could grow to a greater size. Furthermore, it could make just so many more spores and so aid greatly the distribution of the species. Water would be used chiefly for metabolism, not reproduction. At the same time there would be no reason for increased size of the gametophyte. This could remain small and inconspicuous and develop only long enough and large enough to effect fertilization. It would not be necessary for any *one* gametophyte to produce a great many sex organs, for the increased size of the sporophyte would produce so many more spores that the great increase in number of gametophytes would obviate this.

The green sporophyte of Anthoceros referred to above indicates the possibility of the realization of the hypothesis just outlined. The transfer of the starch-making function from the gametophyte to the sporophyte was not made in the case of the Bryophytes. It appears as an accomplished fact in the Pteridophyta. Some botanists believe that forms like Anthoceros were ancestors of Pteridophytes.

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CHAPTER IV

PHYLUM — PTERIDOPHYTA

Introduction. The word Pteridophyte is a combination of two Greek words. The latter part, as we have already used it, means "plant." The first part, from the Greek word, *Pteris* or *Pteridos*, meaning "wing," was their name for ferns. The feathery appearance of fern leaves suggested "wings" to the Greeks. The word *fern* is from the Anglo-Saxon — *fearn*.

Pteridophytes are much larger than Bryophytes. Common ferns (Fig. 39) have underground stems from which arise thread-like roots, while above the ground occur the large conspicuous green leaves. In warmer climates are found "tree ferns" with upright stems, bearing at the top a crown of green leaves. Ferns have a wide distribution and live in a variety of habitats — near the sea and at high altitude; in dry and wet soils; in cold and warm climates; in rocky crevices and in rich soils. The green fern plant is a *sporophyte*, *i.e.*, it produces spores. There is also a separate gametophyte stage present, however, which has the important function of producing gametes. The gametophyte is quite inconspicuous, yet the gametes are essential to the complete life cycle since Pteridophytes exhibit alternation of generations.

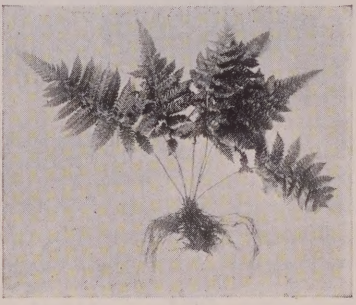


FIG. 39. — A fern. Rhizome is short and hidden among roots; a number of fronds or leaves are shown.

Some types do not, in form, resemble the familiar ferns, yet are similar in general internal structure and life histories.

Pteris

Pteris (Fig. 40) is the type form of the group. In the neighborhood of New York the plants are about two feet high, but in the forests of the northwest (Washington) they may attain the height of 5 feet, in England, 9 feet and in the Andes, 14 feet. Pteris has a wide distribution throughout the world. In dry, open, gravelly places the plants are shorter than when growing in the rich soil of shady woods.

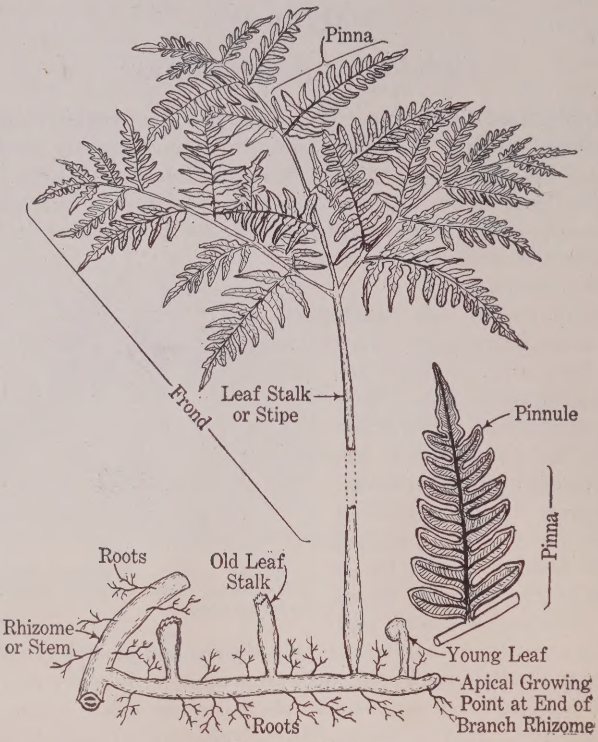

Pinna
Frond
Leaf Stalk or Stipe
Pinnule
Pinna
Roots
Old Leaf Stalk
Rhizome or Stem
Young Leaf
Apical Growing Point at End of Branch Rhizome
Roots

FIG. 40. — Pteris.

The Stem and Roots. Pteris possesses a woody stem (Fig. 40 — Rhizome), which grows a few inches underground and runs parallel with the earth. It is about a centimeter in diameter from side to side. It is brown or brown-black in appearance and is compressed vertically with two lateral ridges. A study of a cross-section of the stem (Fig. 41) of Pteris reveals a variety of structures. The outer surface consists of a layer of epidermal cells. Beneath this layer are several rows of dark, thick-walled, empty cells. They form a tough sheath under the *epidermis* and help to give rigidity to the stem. This tissue is called *outer sclerenchyma.* Inside of these cells is a mass of thin-walled cells which are filled with food. This tissue is known as *parenchyma.*

In the center of the stem are found two somewhat rectangular (in section) masses of cells like those underneath the epidermis, forming the *inner sclerenchyma.* They also contribute to the rigidity of the stem. Arranged around these inner masses are oval or circular masses of cells of different appearance. These groups of cells are *vascular bundles* and consist of specialized elongated cells fitted end to end, possessing the special function of transporting fluids. There is great variety in their structure. To illustrate this, there is (*a*) one type of cell which transports sugar water from the leaves throughout the rest of the plant. These special cells have definite morphological characteristics and constitute what is known as *phloem tissue;* (*b*) another group of cells transports soil water, containing dissolved minerals, from the roots to all parts of the plant. Such cells (of which there may be more than one kind) constitute *xylem tissue.* Other kinds of cells accompany these. In the vascular bundle of Pteris, the large xylem cells and accompanying cells occupy the central part of the bundle while the smaller phloem cells and the cells which accompany them are found toward the periphery. Parenchyma cells occur in the bundle, some associated with xylem cells and some with phloem cells.

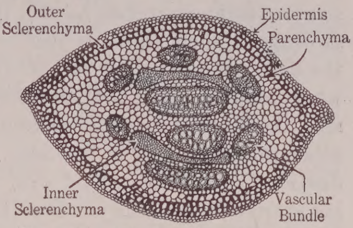


Fig. 41. — Pteris. Cross-section of rhizome.

It should be remembered that solutions are moving slowly in one direction in phloem and in the opposite direction in xylem. The entire bundle is surrounded by a layer of cells called the *endodermis.* The vascular bundles found in the stem of Pteris constitute a very important advance over the stem structure of mosses. We shall find a greater elaboration of xylem and phloem in the stems of the highest plant group, namely, the *Spermatophyta.* Development of wood or xylem makes for greater rigidity, makes possible greater supporting powers and so a greater extension of the leaf system. Continued extension of the vascular system makes possible the supply of soil water needed by this greater leaf mass.

The stem of Pteris grows in the earth like a root and is for this reason called a *rhizome* (root-like). It extends its growth at one end (Fig. 40 — Apical Growing Point), just as the tip-top of a tree does. But unlike a tree, it dies away at the other end. It branches as a tree forms branches, but the branches extend through the earth, growing at their tip ends just as the branches of trees grow. If the decay at the hinder end of the main rhizome reaches the place where one of these branches originates, then the main rhizome and the branch become separated. The branch may send out other branches, and in this way, by a process of vegetative reproduction, ferns may extend over a considerable area if they once get started in a locality. If a farmer wishes to clear such a piece of ground, he must root out every trace of fern rhizome, otherwise any small bit left in the ground may start a new colony. The roots, unlike the roots of a tree, grow out all along the lower surface of the rhizome. As the rhizome grows forward new roots develop. The roots are small and have small branches. Since the stem is underneath the earth, large roots are unnecessary, whereas the tree, with its great upright stem, must have large branching roots extending out in all directions from its base.

Leaf. The leaves of Pteris (Fig. 40 — Frond) are found in groups along the ground. The long rhizome, to which they are connected underneath, is thus indicated. The frond or leaf is divided into the stalk or *petiole*, at the upper end of which is the blade. The blade of the leaf is pinnately (feather-like) divided. There are three main divisions, which is quite characteristic of Pteris. Each portion is variously subdivided into smaller portions called *pinnae*, which are also subdivided into pinnules (Fig. 40).

Superficial examination of a leaflet reveals the midrib, a median linear thickening. Smaller branches of this extend out to the margin of the lobes. The midrib is a smaller division of the vascular system of the petiole, thus connecting the rhizome and leaves. The leaf has an *upper* and *lower epidermis*. Between the two is a chlorophyll-containing tissue called the *mesophyll*. It is in this that the midrib and its branches (veins) run. In the lower epidermis are air pores or stomata. The epidermal layers are protective, while the mesophyll is the region where sugars and starches are made.

Spore Production. The fern plant with its large leaves is a sporophyte or spore-producing plant. Spores are borne in special structures called *sporangia,* found on the under side (Fig. 40) of the pinnules. In Pteris aquilina, the sporangia are borne in a continuous linear group all along the *under margin* of the pinnules and are covered underneath with a narrow fold of tissue reflected from the lower edge. The sporangia (Fig. 42) differ in size. The smaller ones are immature. The largest ones are brownish yellow in color. At the outer end of the sporangial stalk or *pedicel* is a *capsule.* The capsule is somewhat oval in shape and also compressed from side to side. Along one edge is a row of scallop-shaped cells forming the ring or *annulus.* It could more properly be termed a spring. The side walls of the capsule are thin, flat cells. The annulus originates from the pedicel and extends up around the back edge of the capsule and partly around the other end.

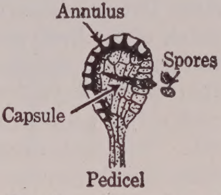


Fig. 42. — Sporangium of fern.

Inside the capsule, spores develop and ripen in the summer. The spore case becomes hard and dry. The annulus, due to this drying, develops considerable tension. Under certain conditions, a rupture occurs in the capsule. The annulus bends back, widening the rupture. It recoils and the spores are discharged. If the wind is blowing at the time, the spores are carried some little distance from the plant. Thousands of these spores are produced by a single plant. Each spore is a single cell. It has been produced asexually from the sporangium, which is the asexual organ of reproduction of the Sporophyte.

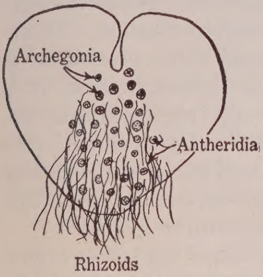
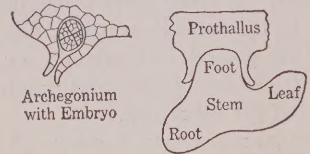


Fig. 43. — Prothallus of fern.

The Prothallus. Falling upon the earth, the spore absorbs water, which softens its hard case. Due to warm air and the absorption of water, the single cell inside is stimulated to divide. Cell division follows cell division. In time there is formed (Fig. 43) a multicellular, small, heart-shaped, flat, leaf-like (thallus) structure about 3 to 5 mm. in diameter and less than 1 mm. thick. It is green in color. On the under side rhizoids develop, and all together it resembles a liverwort such as Marchantia, though much smaller and simpler in structure. It is called a *prothallus*, which means primitive leaf. On the under side develop sex organs, *antheridia and archegonia*, as it is monoecious. The prothalli of some ferns are *dioecious*. The archegonia are formed near the notch of the heart-shaped prothallus. The antheridia are formed farther back among the rhizoids. Each archegonium resembles that of the Bryophytes but is much more simple. There is a neck with a neck-canal, and in the flask-shaped base is a single egg cell. The antheridium is a small case of cells inside which the ciliated male gametes or sperm cells are produced. The sperm are motile and require water in which to swim.

When mature, the sperm escape from the antheridia and swim about in the water. At the time the sperm are discharged from the antheridia, the archegonia of the same prothallus have usually not matured, so that these sperm will probably not fertilize the eggs from the same prothallus. Therefore, although the prothallus is anatomically hermaphrodite, it is not as a rule physiologically so. Self-fertilization is prevented. One sperm enters the archegonium of another prothallus, works its way to the egg or ovum and fuses with it, completing fertilization. The fertilized egg is called an oosperm (ovum-sperm) or zygote.



Archegonium with Embryo

Regions of Embryo

FIG. 44. — Fern. Early development of young sporophyte.

Formation of New Sporophyte. The fertilized egg cell or zygote now begins to divide. It forms two cells, and each of these forms two cells. Each of the four cells (Fig. 44) continues to divide, forming four groups. Let us call these groups A, B, C, D. The cells in group A develop into a structure which remains connected with the prothallus in the region of the old archegonium base. This structure is the *foot* and consists of those tissues which are to act for a time as an intermediary between the green independent prothallus and the new structure about to be described. The cells in group B develop into a young stem; the cells of group C develop into a leaf; the cells of group D, into a root. In a short time, a small plant is discovered clinging to the old prothallus. The little leaf grows up through the notch of the prothallus. The little root grows down into the earth among the rhizoids of the prothallus. The small stem is between them. The little *new plant* (Fig. 45) is still connected to the old prothallus by the foot. Before the new leaf has acquired chlorophyll, this new small plant is dependent upon the prothallus for food for growth. As soon as the new leaf acquires chlorophyll and the new root can absorb mineral materials from the soil and the stem transport these, then the new plant grows rapidly, extending leaf, stem and root far beyond its tiny prothallus, which disintegrates.

Note carefully, however, that it really originated from the fertilized egg. In a sense, the prothallus after fertilization simply nurtures it until it can "carry on" by itself. This little plant is a *new sporophyte.* Eventually it may grow into a large fern plant with its extensive, ramifying underground root-like stem or rhizome, from which will spring multitudes of roots and from which will arise at intervals many large leaves.

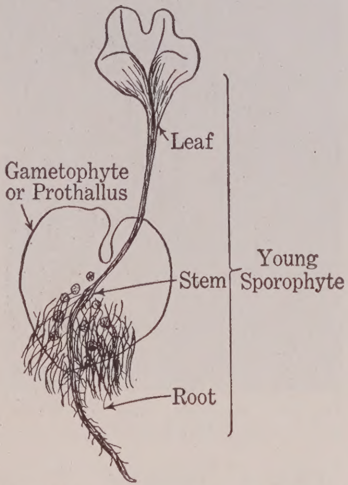


Fig. 45. — Later development of young sporophyte of fern.

Alternation of Generations. Ferns have an *alternation* of *generations.* The large fern plant, with which everyone is familiar, is a sporophyte. This produces spores asexually. A spore develops into a prothallus, which is a gametophyte, bearing sex organs and producing sex cells. The fertilized egg develops into a new sporophyte. However, there is a great contrast to what was found in the Bryophytes. There, the gametophyte was the conspicuous stage, green and independent. During the greater part of its life cycle, a Bryophyte is a gametophyte. The sporophyte is small, inconspicuous, totally dependent on the gametophyte and lives only long enough to produce spores. In Pteris, the gametophyte is small, inconspicuous, short-lived, although it is green and independent because it has to nurture the young sporophyte. The gametophyte is simple in structure — much simpler than the gametophyte of the Bryophytes, for example. The sporophyte, on the other hand, is of great size, green, independent, long-lived and has complexity of structure. The tables are turned. The sporophyte has come into ascendancy, and it has come to stay. The gametophyte in the flowering plants is even less conspicuous, but is still retained because it is needed to perform a vitally important function provided by sexual reproduction.

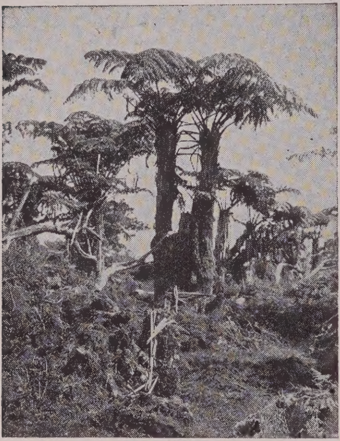


FIG. 46. — Tree Fern. Hawaii. (Photo by Baker, Honolulu.)

Classification

There are about 4500 species of Pteridophytes, and they are divided into three groups or classes: (1) the Filicineae or Ferns, (2) Lycopodineae or Club Mosses and (3) the Equisetineae or Horsetails.

Class 1. Filicineae. The greater number of Pteridophytes belong to the Filicineae. In general, most of them resemble Pteris. The stem is not always long and slender, as in Pteris, but may be short and stocky. The leaves may be less or more subdivided. The greatest living Pteridophytes are tropical forms (Fig. 46) called Tree Ferns, which may grow to be forty feet in height. They have a rough trunk, at the top of which is a crown of large, feathery leaves.

There is a great deal of variation in the extent of the subdivisions of the leaves of ferns. In some forms the leaf blade is not subdivided, as in the rare walking-fern. In others the leaves are more divided than in Pteris. In many forms the sporangia are borne in little clusters, called sori (Fig. 47), having a dot-like appearance on the under surface of a pinnule. In the Cinnamon Fern (Fig. 48) there are two kinds of

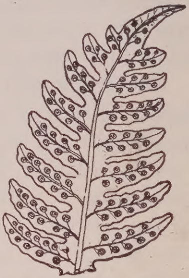


FIG. 47. — Sori on under side of leaflet of Polypodium.

leaves, first, *sterile* or vegetative leaves, which are green, and second, *fertile* leaves bearing sporangia. In the Interrupted Fern, a few pinnules in the middle of the blade are exclusively sporangia bearers. In the Grape Fern, the leaf stalk divides into two branches — one green and subdivided as before and the other spore-bearing only.

Class 2. Lycopodineae. (1) A study of *Lycopodium*, the Club Moss (Fig. 49), one of the Lycopodineae, shows several points of biological interest. It is one of the oldest of Pteridophytes, long antedating the seed plants. The slender stem grows along the ground among dead leaves or just beneath the surface. Here and there it sends up many upright branches. The leaves are small and crowded, giving an appearance resembling moss, and because of this the plant was called a moss. A study of the stem (Fig. 50) reveals important differences from that of Pteris. It is surrounded by epidermis, beneath which is a large cortex with a cylindrical mass of vascular tissue in the center. In the cortex we find schlerenchyma and parenchyma, but it is not broken into separate masses as in Pteris. In this respect Lycopodium shows a more generalized structure than Pteris. In the central cylinder of vascular tissue we find alternating irregular bands of xylem and phloem tissues, which are not scattered about as in Pteris.

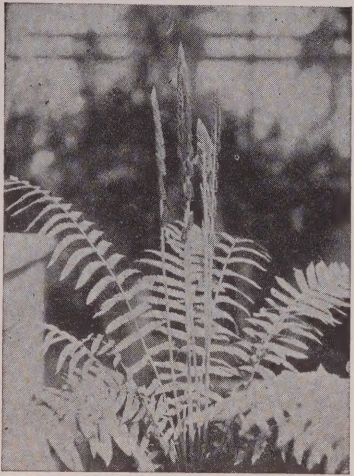


FIG. 48. — Osmunda cinnomomea. Fertile fronds or sporophylls in center surrounded by vegetative fronds. (Photo. by Fread.)

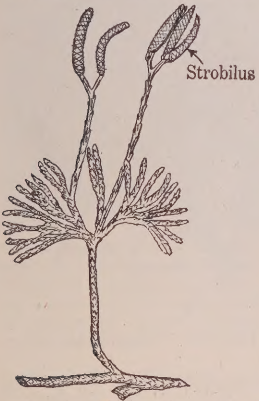


FIG. 49.—Lycopodium. Part of prostrate stem and an erect branch with five strobili at upper end.

At the ends of some branches of certain Lycopods are club-shaped structures.

These are compact masses of special leaves called *sporophylls* because they produce sporangia in which spores are formed. The "club" composed of sporophylls is called a *strobilus* (Fig. 49). The production of spores is thus *limited* to certain definite structures at the upper ends of the branches while the rest of the plant is vegetative. Spores develop into gametophytes.

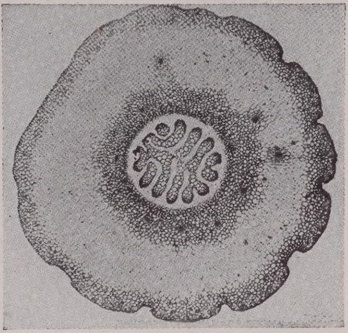


FIG. 50. — Cross-section of stem of Lycopodium. (Photo. by Bratter.)

(2) *Selaginella* (Fig. 51) belongs to another order of the Lycopodineae. It is a delicately-branching little plant, growing prostrate. Rows of small moss-like leaves grow out flat from each side of the stem. At the tip of the branches are also *strobili* which are semi-erect. A matter of especial interest is this, namely, that two kinds of spores are produced in the strobilus, — *small* forms which are called *microspores* and *larger* ones called *megaspores.* On germination, each microspore develops into very simple *male gametophyte* or *microgametophyte,* composed chiefly of a *single antheridium* which produces biciliate sperm. The *megaspore* develops into a simple, *female gametophyte* or *megagametophyte,* which produces *two* or *three archegonia* with one egg in each. This phenomenon occurs also among a few other Pteridophytes, but it is not the rule. We shall consider this matter later and connect it with structures found in lower Seed Plants.

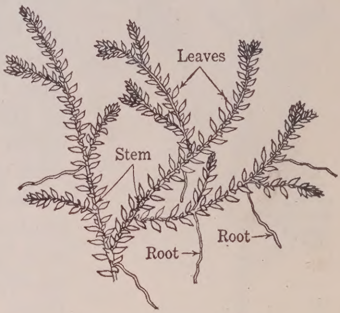


FIG. 51. — Selaginella.

Class 3. Equisetineae. *Equisetum* is an example. It is often found on the dry gravel along the road or by the side of railroad tracks and is commonly known as the horsetail or scouring rush. The rootstock or stem lives in the earth from year to year. From it arise vertical stems of two kinds: *vegetative* and *reproductive.* In some species both are on one stalk. One is a *vegetative* or sterile stem (Fig. 52 *A*), which is fluted and feels harsh to the touch, due to the silica in it. Nodes appear along its length. At each node is a circle of diminutive leaves. From the axils of these grow green stems, also with nodes surrounded by whorls of small scale leaves. Functions carried on by the leaves of ferns are here carried on by these sterile stems. Spores with elaters attached are produced in *sporangia* which occur in *cones* or *strobili,* at the ends of special *fertile* stems (Fig. 52 *B*). The spores look alike but are physiologically differentiated, because one type produces male gametophytes and the other, female gametophytes.

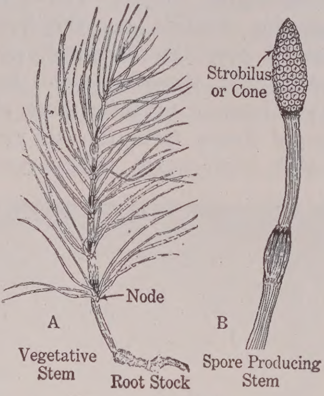


Fig. 52. — Equisetum.

Evolution of Vascular System. A comparative study of the vascular tissues of Pteridophytes shows an interesting series starting with simple conditions and ending in an arrangement like that of higher plants, the *Spermatophyta.* For example, in *Gleichenia* (Fig. 53), one of the Filicineae, the xylem vessels occupy the center of the vascular region and are surrounded by the phloem. The vascular region is restricted to the central portion of the stem and is called the *stele.* In *Lycopodium* (Fig. 50) (Lycopodineae) we found that the stele was composed of irregular alternating bands of xylem and phloem. In *Osmunda* (Fig. 54) (Filicineae) we find that the vascular tissue is in definite groups of cells arranged radially, having the phloem outside and the xylem toward the center of each mass. And this is the arrangement usually found in many of the seed plants.

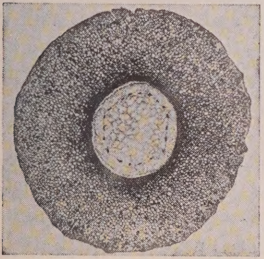


Fig. 53. — Cross-section of stem of Gleichenia. Central cylinder of vascular tissue. Xylem in center of this, surrounded by thin ring of phloem. (Photo. by Martin.)

Summary of Pteridophytes

Pteridophytes are very ancient plants and in bygone ages formed great forests. The carpet-like moss plants with shallow-growing rhizoids and simple stem and leaves have not dominated over the Pteridophytes, which explore deeper into the earth with their roots and bear an enormous increase of leaf area because of their more rigid stems. This great leaf expanse draws from the air great volumes of carbon dioxide, which, with water, makes greater supplies of starch and with added nitrates builds up more protoplasm, more cells and larger plants.

Pteridophytes were once more dominant plants than they are today. This was back in the latter part of the Palaeozoic Era of the Earth's history, during the Carboniferous Period millions of years ago and sometimes called the "Age of Coal." The climate was warm and moist and there existed great swamps where now are coal beds. It has been suggested that the atmosphere contained a greater percentage of carbon dioxide than at present. It is known, today, that greater plant growth takes place in air containing a slight excess of CO_2. A warm, moist atmosphere containing an excess of CO_2 would favor great plant growth. The true ferns were represented as an undergrowth, but there were great Lycopod trees, Lepidodendrons and Sigillarias, 100 feet or more in height, with trunks 3 feet or more in diameter and with spreading roots whose branches ramified through the mud of the swamps. Equisetums, called Calamites, were present also, some over 100 feet in height, with great, hollow trunks somewhat like those of bamboo. In spore-bearing time, the air was probably filled with clouds of spores. There existed also large plants formerly considered as ferns but now known as Pterid-

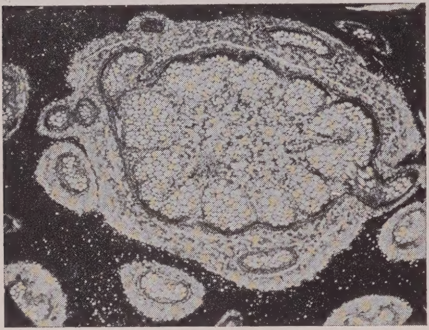


FIG. 54. — Cross-section of stem of Osmunda. (Photo. by Martin.)

osperms, primitive seed plants. The swamps teemed with animal life, many types being destined to evolve into terrestrial forms. Dragon-flies and cockroaches existed, but there were no bees, moths or butterflies, and there were no flowering plants. The climate changed during the following Permian period and the great Lycopods and Equisetums disappeared, but smaller forms of the same groups clung to life during all the changes of climate throughout the ages and transmitted their kinds on to present days.

In our study of Bryophytes it was found that there are two kinds of gametophytes, male and female. In some ferns there are also two kinds of prothalli, or gametophytes, male and female. The spores that form them look alike as in Equisetum, but there are real differences between them. In Selaginella there is a visible difference between the spores, *i.e.*, *microspores* and *megaspores*. They come from different sporangia — microsporangia and megasporangia. Sporangia are sporophyte structures. Therefore, sexual differentiation has extended in a sense to the preceding sporophyte generation. Moreover, the microspore develops into a male or *microgametophyte* and the megaspore into a female or *megagametophyte* — both growing while still attached to the sporophyte and both very small. This is similar to what is found in the higher and dominant seed plants, only there the diminution is carried even further. Both gametophytes of Selaginella depend on the sporophyte for nourishment — a condition we will find to be true in the Spermatophytes or seed plants. The developing microgametophyte of Selaginella becomes dislodged from the place where it is formed, at the upper end of the strobilus, and falls to sporophylls farther down and comes into contact with a developing megagametophyte, so that the liberated sperm cells can easily fertilize the egg cells in the archegonia. The bringing together of sperm and egg cells (gametes) *does not depend so much on the motility of sperm* as in cases hitherto studied. *The male gametophytes are in their entirety brought into close juxtaposition with the female gametophytes, so that the sperm are near to the eggs.* A further elaboration of this process is characteristic of the higher plants.

The vegetative functions of Pteridophytes are carried on by the sporophyte, which has come into the ascendancy in this group. In the Bryophytes it was small, inconspicuous and dependent on the gametophyte. The gametophyte stage in Pteridophytes is retained, though reduced in size. It is green in some cases and so physiologically independent but it is short-lived. It is rather dependent in Selaginella. It is retained in Pteridophytes for the production of gametes and the interpolation of a sexual phase between successive sporophyte stages. The retention of the sexual phase appears to be necessary.

The greater development of the sporophyte means more roots that draw upon greater resources of mineral constituents for protoplasm; the stem, increasing in size or extent, can support a greater display of leaves and can conduct the soil ingredients to them, and the greater leaf expanse can make more starch and more protoplasm and provide for a greater plant. In addition to the above, the *new sporophyte has developed the possibility of being perennially active.* There is a great increase in number of sporangia and a much greater multiplication of spores, which, being scattered farther, spread the species into new environments, where individuals are subjected to new conditions which may modify them and so set the stage for the origin of new types. The adoption of the green leafy habit by the sporophyte generation of Pteridophytes was of great evolutionary significance.

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CHAPTER V

PHYLUM — SPERMATOPHYTA. PART I

FLOWER, FRUIT AND SEEDS

A Seed Plant. The Spermatophyta are *Seed Plants.* Sometimes they are called the Flowering Plants. But the word *flower* has a variety of meanings. For example, according to one idea, the strobilus of Equisetum (Fig. 52 *B*) might be considered a flower, but it is not a seed plant. According to another definition, pine trees would be excluded from flowering plants although they have seeds. It is altogether more satisfactory to define this group as those plants which have seeds.

Seed plants constitute the most conspicuous vegetation of the present stage in the evolution of the earth. They furnish man with the larger part of his food supply and other products essential to the existence of civilized people. The formation of the *seed* is of the greatest importance in the evolution of the dominant position occupied by the Spermatophyta.

They are often called *Phanerogams,* plants whose organs and methods of reproduction are *very evident.* The Thallophyta, Bryophyta and Pteridophyta were called *Cryptogams* because it was thought their organs of reproduction were *obscure.* The facts are quite the opposite of this, *i.e.*, the organs and methods of reproduction are more easily studied in the so-called Cryptogams.

There are two groups of Spermatophyta: (*a*) Gymnosperms and (*b*) Angiosperms. The plants of the first-named group have naked or exposed seeds and those of the second group, hidden seeds.

CLASS I. GYMNOSPERMAE

The Gymnosperms are survivors of more ancient forms than the comparatively modern and specialized Angiosperms. Fossil Gymnosperms have been found in the coal beds of the Carboniferous Age.

Two prominent groups of the Gymnosperms are (1) the Cycads and (2) the Conifers. Cycads grow in or near the tropics; Conifers, as a rule, grow in the temperate zone.

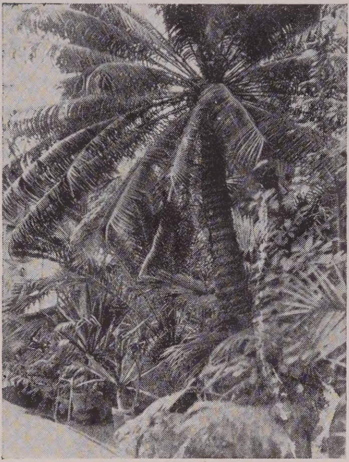

Fig. 55. — Cycas celebica. N. Y. Botanical Gardens. (Photo. by Fread.)

Order 1. Cycadales — Cycads

Morphology. A Cycad (Fig. 55) resembles a tree fern in appearance. There is an upright trunk with a crown of large, tough, pinnately-divided leaves at the top of the plant. The leaf may survive more than one year. The stem has a large pith, cylindrical zones of vascular tissue, and a conspicuous cortex containing a great amount of stored starch. New stem tissue develops from special formative tissue called the cambium.

Reproduction. The plant is dioecious, *i.e.*, some individuals are male and others are female. In both cases, spores are produced in a strobilus or cone at the apex of the stem. Each strobilus (Fig. 56) has a central axis surrounded by scale-like sporophylls, *microsporophylls* (Fig. 57) in male or *staminate* cones and *megasporophylls* in female or *carpellate* cones, and each type of sporophyll develops sporangia; *microsporangia* and *megasporangia*, respectively. Microspores are produced in *microsporangia* and megaspores in *megasporangia.*

While still within the microsporangium, the microspore develops into a three-celled male gametophyte. From its similarity to homologous bodies in Conifers and Angiosperms, *these* microspores (or three-celled gametophytes) are known as *pollen grains.* Many thousands of these are produced by a single male cone. When freed from the cone, they are carried away by air currents. Some, by chance, may fall on the strobilus of a female tree. Each

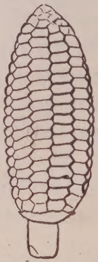

Fig. 56. — Male strobilus or cone of Zamia.

megasporophyll develops on its upper surface two megasporangia, consisting of tissue called the *nucellus,* around which develops tissue called the *integument.* Within each nucellus is a *spore mother cell* which develops into *four megaspores,* three of which abort; the remaining one develops a *megagametophyte* (Fig. 58), at one end of which are two or more archegonia. So that around the mature megagametophyte is a thin layer of tissue, the *nucellus.* Outside of this is a thicker tissue, the integument, consisting of an inner hard *sclerotesta* and an outer fleshy *sarcotesta,* almost entirely covering the nucellus except for a tubular hole called the *micropyle.* The canal leads to the outer end of the nucellus. At this inner end of the canal, just outside the nucellus, is a little space called the pollen chamber. Between the nucellus and the necks of the archegonia is a small space also, called the archegonial chamber.

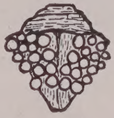

Fig. 57. — Microsporophyll of Zamia with sporangia.

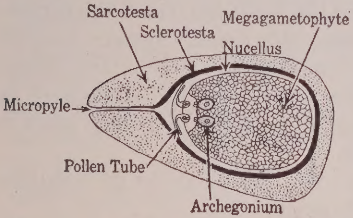

Fig. 58. — Megasporangium (♀) of Zamia. From Smith and Others, *General Botany,* Revised Edition, copyright 1928, by The Macmillan Company, reprinted by permission.

When the pollen grains are shed, a few may land on a carpellate cone whose sporophylls have opened out to catch them. The pollen grain sifts down to the opening of the micropyle, into which it is drawn, and so down to the pollen chamber just outside the nucellus. The whole process of transportation of the pollen is called *Pollination,* a *distinguishing seed-plant feature.* Each pollen grain (now a three-cell male gametophyte) develops a thread-like pollen tube which grows into the nucellus, absorbing food from it, and so into the archegonial chamber. From the pollen tube two sperm cells which have later developed in this microgametophyte are discharged into the chamber. Each sperm cell (Fig. 59) is cone-shaped with a spiral band of cilia about it. They swim, spinning about, in the archegonial chamber. One works its way

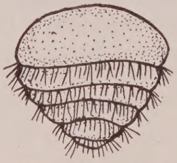

Fig. 59. — Sperm cell of a Cycad. From Smith and Others, *General Botany,* Revised Edition, copyright 1928, by The Macmillan Company, reprinted by permission.

down the neck of an archegonium and fertilizes the egg there. A zygote is the result, and from this, an embryo plant develops (Fig. 60). The remaining part of the megagametophyte, the endosperm,[1] stores up a reserve supply of food for the young embryo. The *hard* inner and the outer *fleshy* integuments form two seed coats. They are part of the old sporophyte; the endosperm is part of the megagametophyte and the embryo is a new young sporophyte, so that three generations are represented here. All these parts constitute the *seed.*

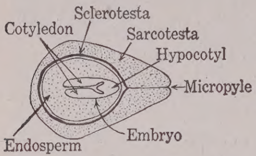

FIG. 60. — Seed of Cycad with embryo. From Smith and Others, *General Botany*, Revised Edition, copyright 1928, by The Macmillan Company, reprinted by permission.

After the seeds fall out of the carpellate cone, they usually remain *dormant* for a time, but *later germinate* under proper conditions. Life activities speed up; the endosperm is used as food in the development of the embryo to a stage when it can maintain itself independently.

Comparison with Selaginella. At this point let us compare Cycads with Selaginella, a Pteridophyte.

1. In Selaginella microsporophylls and megasporophylls occur on the same strobilus. In Cycads there are two kinds of strobili, male and female. Microspores are developed in microsporangia on microsporophylls and megaspores in megasporangia, etc.

2. The microspore develops into a miniature male gametophyte, for the most part within the microsporangium, and the megaspore develops into a female gametophyte, still within the megasporangium. Both gametophytes are homologous[2] with the prothallus of the fern and with the green sex-organ-bearing Marchantia plant.

3. Motile sperm are produced, but in the Cycad their *free swimming range is very much restricted.* A new method is introduced to effect this.

4. In the Cycad, a new structure appears, the Seed, formed within the female gametophyte and its megasporangium while the latter is still connected with the old sporophyte.

5. It is evident therefore, that a *Seed* involves first, the embryo sporophyte; second, its parent gametophyte and third, the parent sporophyte from which the latter developed.

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[1] The so-called endosperm of Cycads has the same general appearance and function as that of Angiosperms, but the two are not strictly homologous.

[2] See page 194.

Order 2. Coniferales — Conifers

The second group of Gymnosperms are the Conifers, such as pine trees, hemlocks, spruces (Fig. 61), cedars and firs. They usually possess a tall, straight trunk with radiating branches: longer ones below and shorter ones toward the top, giving a cone-shaped effect to the whole tree — a form which resists very well the destructive effect of heavy weights of snow, so prevalent in the habitat occupied by many Conifers. The leaves are green scales or needles, a form admirably adapted to resisting cold.

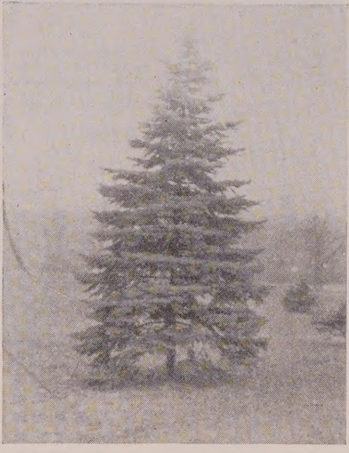

Fig. 61. — Blue Colorado Spruce. N. Y. Botanical Gardens. (Photo. by Fread.)

Reproduction. Reproduction is similar in many respects to that of Cycads. In the Pine, reproductive organs are produced in two kinds of cones: male and female, *i.e.*, *staminate* and *carpellate*. The staminate cones (Fig. 62 *A*) are small and do not persist very long. Each is composed of lateral scales (Fig. 62 *B*) (microsporophylls), which possess microsporangia in which microspores or pollen grains (Fig. 62 *C*) are produced. Pollen is transferred to the carpellate cones by the wind, and for this purpose an immense amount of pollen is produced by a conifer forest in the spring. The carpellate or female cones (Fig. 62 *E*) in some species grow to a very large size. The cone scales, or megasporophylls (Fig. 62 *F*), become hard and woody. Each cone scale produces two megasporangia, consisting of a megaspore mother cell surrounded by tissue called the nucellus, which in turn is surrounded by the integument. The megaspore mother cell gives rise to four megaspores, three of which abort. After a series of divisions a female gametophyte (Fig. 62 *G*) is organized from the remaining megaspore with two or more archegonia in each of which is an egg. The pollen grains, carried by the wind, fall on the upper surface of the edge of the megasporophylls and fall down to the micropyle in the integument, where they germinate and form *pollen tubes* (Fig. 62 *D*). Each pollen tube (Fig. 62 *H*) penetrates the nucellus and sends a *male nucleus* down to the egg cell in each archegonium. *There are no free-swimming sperm present.* An embryo is formed in each archegonium, but only one usually matures. The mature *embryo* (Fig. 62 *I*) is inside the megagametophyte, with the *endosperm.* Around them is the *thin* paper-like nucellus and around this the integument which becomes the hard seed coat. Attached to it is a scale thus adapting the seed for wind dispersal. The seed is detached from the cone scale, when the tree is shaken by the wind, and being light in weight, is carried some distance by air currents. Or it may be distributed by seed-eating Mammals, such as squirrels. Conifers are ancient plants and there are not many species of them. Nevertheless they flourish vigorously in the cooler regions of the earth, both in the northern and southern belts of the temperate zones.

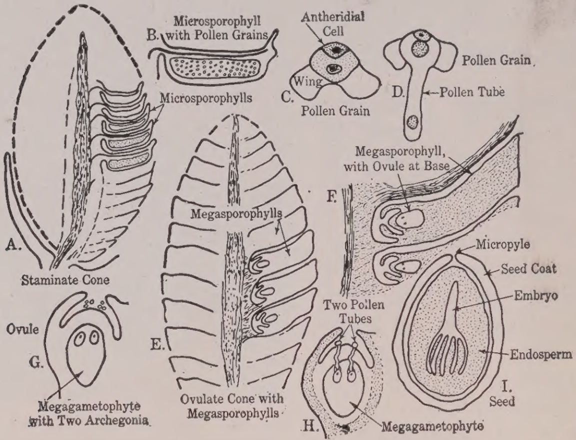
B.
Microsporophyll with Pollen Grains
Antheridial Cell
Wing
C.
Pollen Grain
Pollen Grain
D.
Pollen Tube
Microsporophylls
A.
Staminate Cone
Megasporophyll, with Ovule at Base
F.
Megasporophylls
Micropyle
Seed Coat
Embryo
Endosperm
I.
Seed
Ovule
G.
Megagametophyte with Two Archegonia
E.
Ovulate Cone with Megasporophylls
Two Pollen Tubes
H.
Megagametophyte

FIG. 62. — Reproduction in the pine. From Sinnott's *Botany*, McGraw-Hill Book Co., reprinted by permission.

Summary. In review, the life history of the Conifers is similar to that of the Cycads and to a certain extent to that of Pteridophyta and Bryophyta.

1. In the Gymnosperms (Cycads and Conifers) there are stami-

nate or male cones (strobili) and carpellate or female cones. The staminate cones possess microsporophylls and the female cones, megasporophylls.

2. Microspores are produced in microsporangia on the microsporophylls, and megaspores are produced in megasporangia on the megasporophylls.

3. The microspore develops into a diminutive male or microgametophyte, while the megaspore develops into a simple female or megagametophyte, with two or three archegonia, each with one egg.

4. Pollen grains are shed from the male cones and dispersed by air currents. If the pollen grain of a Conifer reaches a female gametophyte, it develops a pollen tube. But in the case of the Cycad, the pollen produces free-swimming sperm. In the Conifer, there are *non-motile sperm cells,* which are produced in and carried to the egg cell by growth of the pollen tube.

5. While the method differs in the two cases, the end result is the same, namely, the fusion of a male sex cell with a female sex cell, resulting in the formation of a fertilized egg or zygote, the first stage in the life of a new individual (sporophyte).

6. With the appearance of spore dimorphism, earlier seen in Selaginella, there develop two kinds of very diminutive gametophytes, one of which has the job of producing sperm cells and the other, egg cells.

7. Motile sperm, noted first in Oedogonium, are present in all groups of green plants up to and including Cycads, although absent in the next higher group, the Conifers.

8. The retention of free-swimming sperm is not essential, provided some mechanism is present to insure the union of male and female sex cells. The substitution of the pollen-tube method of fertilization is a specialization which is peculiarly adapted to the Conifers and higher Seed Plants. It makes more certain a tremendous production of embryo plants (seeds) and has played no small part in bringing about the world-wide dominance of the Angiosperms.

CLASS II. ANGIOSPERMAE

Definition. The Angiosperms form seeds inclosed in special parts of the megasporophyll, *i.e.*, they have hidden seeds, hence the name. They are divided into two great groups: A, *Dicotyledons*

(Fig. 63) and B, *Monocotyledons* (Fig. 64). As examples of the first, we have such plants as beans and peas, and apple, oak and maple trees. Examples of the Monocotyledons are rice, corn, wheat and palm and bamboo trees. The word *cotyledon* refers to a seed leaf formed in the seed and related to the nourishment of the embryo plant at time of germination. Dicotyledons possess two of these seed leaves and monocotyledons have one.

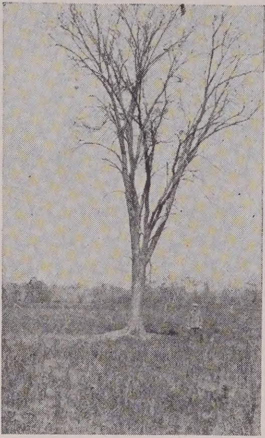

FIG. 63.—Elm Tree. (Photo. by Fread.)

Morphology of the Flower. Angiosperms possess a root, stem and leaf system, which will be discussed in detail presently. Since we have just been studying reproduction in the Gymnosperms, it seems best to introduce at this point a study of the organ of reproduction in Angiosperms, *i.e.*, the flower. This at first appears to be a new structure, unrepresented in the lower phyla and in the Gymnosperms. A study of the flower, however, reveals the fact that its essential parts are microsporophylls and megasporophylls, each sometimes in separate flowers, both very often in the same flower. In addition to the above, there are frequently present special leaf-like parts called *petals* and *sepals*, the first-named being usually colored white, pink, etc., and the latter, green. Petals and sepals, if present, constitute a *perianth*, although some flowers have no perianth.

A typical flower possesses four whorls of parts (Fig. 65). These usually occur in groups of three or multiples of three

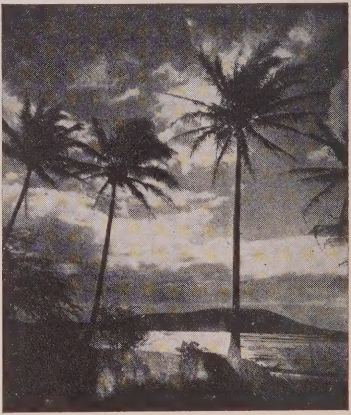

FIG. 64.—Coco Palms—Hawaii. (Photo. by Baker, Honolulu.)

in the Monocotyledons and in five (sometimes in four) or multiples of five in the Dicotyledons. The *calyx,* composed of green *sepals,* is the outermost series. Inside the calyx is the *corolla* composed of *petals,* which may be red or blue, etc. Inside the petals are the *stamens* or *microsporophylls.* Each *stamen* has a long stalk or *filament* at the end of which is a microsporangium, the *anther,* in which *microspores* or *pollen grains* are produced. Inside the whorl of stamens is the last set of parts, the *carpels* or *megasporophylls.* These possess *megasporangia* in which *megaspores* are developed.

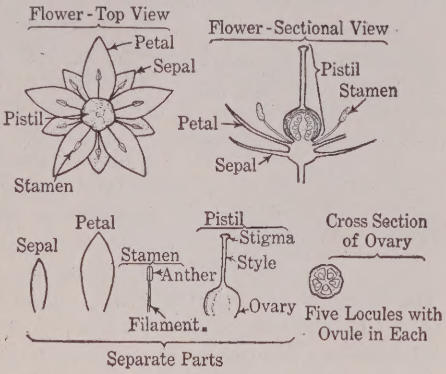
Flower - Top View
Petal
Sepal
Pistil
Stamen
Flower - Sectional View
Pistil
Stamen
Petal
Sepal
Sepal
Petal
Stamen
Anther
Filament
Pistil
Stigma
Style
Ovary
Cross Section of Ovary
Five Locules with Ovule in Each
Separate Parts

FIG. 65. — Parts of typical dicotyledon flower. From Sinnott's *Botany,* McGraw-Hill Book Co., reprinted by permission.

In the willows the flowers have no perianth. These trees are dioecious, *i.e.,* one type of tree produces only staminate flowers or, as they are commonly called, catkins. The other type of tree produces only carpellate catkins. The catkins also appear before the leaves or simultaneously with the leaves. In the sycamore there is neither calyx nor corolla and on the same tree are both staminate and carpellate catkins, but they are different flowers. Separate staminate and carpellate catkins occur in the birch and walnut, *i.e.,* both types of flowers (Fig. 65 *A*) on the same tree. In the apple, cherry and pear, the flowers possess all four series of parts.

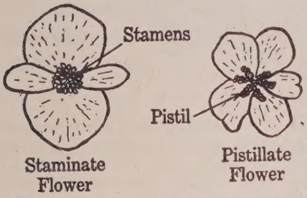
Stamens
Pistil
Staminate Flower
Pistillate Flower

FIG. 65 *A.* — Staminate and pistillate flowers of Begonia. Both found on same plant. Such flowers are *imperfect* since neither possesses *all* the *essential* organs for seed formation. Stamens *and* pistil are *essential* organs. Sepals and petals are *not essential,* although a flower without them is *incomplete.*

A strobilus of lower plants, such as Equisetum, has a central axis around which sporophylls are arranged spirally. Some angiosperm flowers retain something like such an axis with sporophylls similarly arranged. If the axis were shortened to a mere knob, a great reduction of sporophylls would necessarily follow and these would tend to be arranged in circles instead of spirals. Flowers are borne at the end of branches. The floral parts are borne on an expanded end branch known as the *receptacle,* which is thought to be a much-shortened axis of a strobilus and the whole flower and its receptacle homologous with a strobilus. Sometimes the sepals are united, as may be the petals, the stamens and the carpels. The flower of the primrose has a united calyx and corolla. The most common type of fusion is that of the carpels, forming what is known as a *pistil* although some pistils consist of only one carpel. The pistil (or carpel) has a knob on the top called the *stigma.* It is sticky and sugary. Below the stigma is a connecting neck or *style* and below at the base is an enlarged part called the *ovary.* A cross-section of the ovary (Fig. 66) reveals one or more chambers within. These chambers or *locules* contain *ovules.* Often but one ovule occurs in a locule. Each ovule (Fig. 67) usually consists of two integuments, outer and inner, inside of which is the nucellus containing the megaspore mother cell. The ovule is connected to the wall of the ovary by a tiny stalk called the *funiculus.* At one end of the ovule a passageway occurs in the coats and extends to the nucellus. This passageway is the *micropyle.*

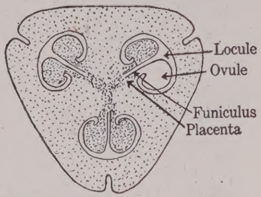

Fig. 66. — Cross-section of ovary of young Lily flower.

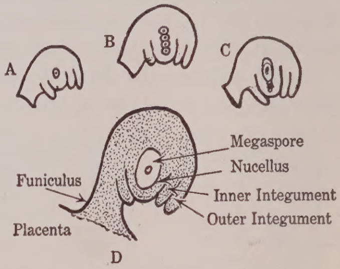

Fig. 67. — Development of megaspore. *A* — Shows megaspore mother cell within nucellus of young ovule; *B* — It has divided twice, forming four megaspores; *C* — Three of these degenerate; *D* — The remaining megaspore grows larger and will become the female gametophyte as shown in Figs. 69 and 70. From Smith and Others, *General Botany,* Revised edition, copyright, 1928, by The Macmillan Company, reprinted by permission.

Flowers are necessary for the production of seeds which contain embryo plants. These are the result of fertilization or the union of male and female sex cells. In the lower plants we found that water is necessary for fertilization, and enables the sperm to swim to the egg cells. In the flowering plants it is necessary for pollen to be deposited on the stigma of the flower by other agents. The transfer of pollen from stamens to pistil is called *pollination.*

Pollination. Some flowers are so constituted that the stigmas are pollinated from the stamens of the same flower. This is *self* or *close*-pollination. The legume plants, peas, beans, peanuts (Fig. 68), are examples. Self-pollination tends to maintain continuance of plant traits, and this is very desirable at times. *Cross-pollination* tends to introduce variation. In many trees there are two kinds of flowers — (*a*) staminate and (*b*) pistillate. Pollen is produced in great quantities and is carried about by air currents, so that the pistillate flowers are for the most part pollinated by pollen from other trees. In other flowers, insects effect cross-pollination. It has been thought that they are attracted by the gayly colored petals although recent experiments throw doubt on this supposition. At any rate, bees do collect pollen and nectar from flowers; and on such expeditions they visit flower after flower and do transfer pollen from the stamens of one flower to the pistil of another. They also probably transfer pollen from one to a different species. If this happens, it is usually ineffective. In some flowers, self-pollination is prevented, for the stamens and pistil do not mature at the same time. There are many devices to prevent self-pollination. The Date Palm has been cultivated for over fifty centuries. It is dioecious, so that to produce fruit, pollen from the flowers of the *male* tree must be transferred to the pistils of the *female* tree. This has been known ever since date culture has been practiced. Theophrastus, an early Greek botanist living in the time of Aristotle, described how the date grower shook the "dust" of the male flower over the "fruit" of the female flower.

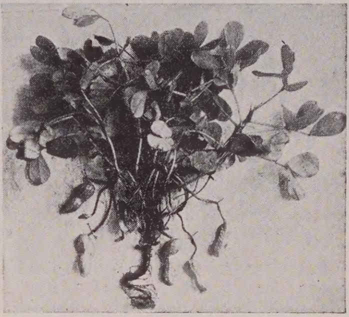
FIG. 68. — Peanut plant. The flowers are self-pollinated. They are covered with earth, and seeds form in earth.

In 1876 Charles Darwin published a book on "The Effects of Cross and Self Fertilization in the Vegetable Kingdom." He concluded that cross-pollination produced better results. Darwin used the word *fertilization* for what is better termed *pollination.*

Fertilization (Fig. 69). We have learned to define fertilization as the union of a male and female gamete, resulting in a zygote. When a pollen grain (microspore) falls on the stigma of a flower of the same species, it develops a *pollen tube.* This is a long, slender filament which grows down the style to the ovary, into a locule and through a micropyle of an ovule into and through the nucellus around a female gametophyte and so into the latter. The pollen tube has only three nuclei and no cell walls. This three-nucleated microscopic thread-like filament is the male gametophyte of the flowering plants. It is homologous[1] with the male Marchantia plant and the prothallus of the fern. One of its nuclei is vegetative, and the other two nuclei are sex nuclei, *i.e.*, may be considered sperm nuclei. They are not motile. This arrangement is an advantage because fertilization may be effected in flowers at the ends of branches *away from* the ground. The seed plant has been freed from restrictions which keep the plant at the earth's surface. While the pollen tube has been developing, the single-celled megaspore mother cell (Fig. 67), within the nucellus of the ovule has divided twice, forming four megaspores, three of which degenerate. The fourth megaspore divides three times (Fig. 70), forming an eight-nucleated female gametophyte or embryo sac. This is homologous with the female Marchantia plant, with the female prothallus of the fern, the female gametophyte of Selaginella, of the Cycad and of the Pine.

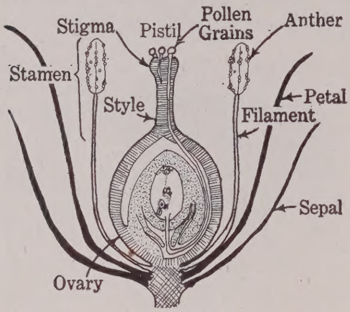

FIG. 69. — Parts of a flower. Pollen grains (microspores) are shown on stigma. The right one has formed a pollen tube which has penetrated the ovule and discharged two male nuclei into the female gametophyte. From Sinnott's *Botany,* Revised edition. McGraw-Hill Book Co., reprinted by permission.

Three nuclei of this embryo sac move to the end opposite the micropyle and soon degenerate. Two others, called *endosperm nuclei*, take up a position near the center and the other three arrange themselves near the micropyle. *One* of *these three* is the egg nucleus. Its neighbors soon degenerate. The pollen tube, as stated, penetrates the nucellus around the embryo sac, its vegetative nucleus disintegrates and the two sperm nuclei are delivered to the embryo sac. The first sperm nucleus moves up to the two endosperm nuclei and all three unite. The other sperm nucleus unites with the egg nucleus and fertilization is complete. Both fused nuclei now initiate a series of cell divisions.

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[1] See page 194.

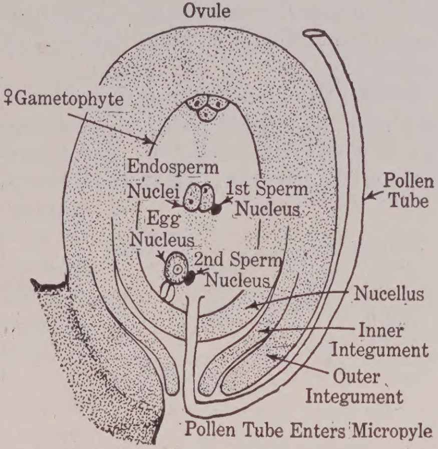

Ovule
♀Gametophyte
Endosperm
Nuclei
1st Sperm
Nucleus
Egg
Nucleus
2nd Sperm
Nucleus
Pollen
Tube
Nucellus
Inner
Integument
Outer
Integument
Pollen Tube Enters Micropyle

Fig. 70. — Enlarged diagram of the ovule shown in Fig. 69. From Sinnott's *Botany*, Revised edition. McGraw-Hill Book Co., reprinted by permission.

Formation of Seeds. The cells formed from the egg-sperm nucleus form the small *embryo plant.* The other nucleus formed by the union of the endosperm nuclei and the first sperm nucleus form what is known as the *endosperm.* This usually attains considerable size in monocotyledon seeds (Fig. 71), being many times larger than the embryo and consisting of food for the use of the embryo at the time of germination. In dicotyledon seeds the endosperm is usually soon absorbed and in its place, two *seed leaves* (Fig. 72) are developed from the embryo stem. These increase to a relatively great size (as in beans), being filled with food to be used by the embryo at germination. In either case the material for endosperm or cotyledons is delivered to the ovule through its funiculus and thence to the embryonic structures within. Immediately around the embryonic structures is the

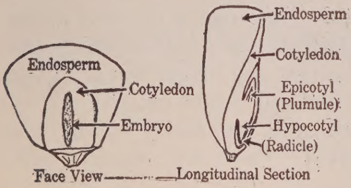

Endosperm
Cotyledon
Embryo
Endosperm
Cotyledon
Epicotyl
(Plumule)
Hypocotyl
(Radicle)
Face View
Longitudinal Section

Fig. 71. — Corn grain.

nucellus and outside this are the integuments. In a short time, the floral parts wither away, the nucellus and integuments become hard, dry and impervious to water, and the seed with its complement of food is prepared to pass long weeks during the fall and winter in a dormant condition. It will " awaken " into active life, at germination.

Seeds. (*a*) *Monocotyledon* (Fig. 71). On one face of the corn seed near the pointed end is an oval-shaped area along the midline of which is the embryo. The greater part of the volume of the seed is endosperm. This seed is covered with a seed coat, which consists of the dried old *wall of the ovary* and the integuments. So that although a grain of corn is mostly seed it is also a fruit. Between the embryo and the endosperm is the single cotyledon which partially surrounds the embryo below in addition to being connected with it posteriorly. The greater part of the embryo is called the hypocotyl. This is the portion below the cotyledon. The portion of the embryo above the cotyledon is called the epicotyl. The portion of the plant above ground develops chiefly from epicotyl. The lower tip of the hypocotyl is the radicle or primary root. The food stored in the endosperm is transferred to the embryo during its early development.

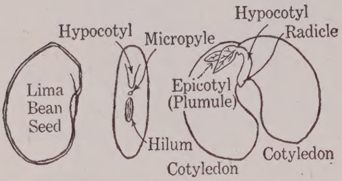


FIG. 72. — Lima bean seed.

(*b*) *Dicotyledon* (Fig. 72). The lima bean seed is large enough to enable us to understand the structure of a dicotyledon seed. The seed was taken from a pod (fruit) which is the dried wall of the ovary. The tough coats about the seed itself are the remains of the old integuments of the ovule. One edge of the seed shows a depression and on the face of this, a scar or hilum where the ovule was attached to the funiculus; at one end of this is a little pit, the micropyle, through which the pollen tube entered. After soaking in water the seed coats are easily removed. We find *two* large, thick cotyledons or seed leaves. These are connected with and are part of the embryo.

Sugar and proteins and fats derived from the bean plant were transferred to these seed leaves during seed formation and stored there for the future use of the embryo. At one end between the cotyledons is the embryo proper. The greater part of it below the cotyledons is the hypocotyl. The portion of the embryo above the cotyledons is the epicotyl. We see the embryonic leaves at this point. The endosperm in dicotyledon plants is not usually prominent. Its function as a storehouse of reserve food for the growing embryo is taken over by the cotyledons. Seeds contain food in concentrated form and there is very little water in them. Because of the concentrated food, man uses seeds as his staple food supply. First in importance is wheat, then corn, rice, oats, rye, beans, peas, etc. Seeds contain proteins, starches, mineral salts, and some contain valuable oils and some contain vitamins.

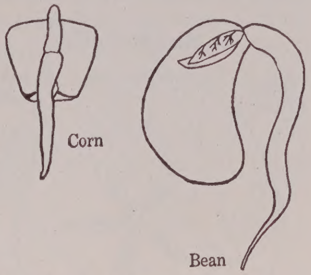


FIG. 73. — Germinating seeds.

Germination (Fig. 73). When seeds are surrounded by the proper temperature, moisture and air, they will germinate. This means that the little embryo will sprout or start growing. Peas may be planted in cold soil while warm soils are necessary for corn. Most seeds have to undergo a period of rest and dryness before sprouting. Well-dried corn gives better crops than undried seed. Germination takes from a few days to two weeks. The cotyledons of the pea remain in the earth, but those of the bean are raised above the earth. The cotyledon of the corn serves as an organ to transfer digested food, *i.e.*, sugar, fat and proteins, from the endosperm to the growing embryo. The food stored in the cotyledons of the bean is also digested and transferred to the growing embryo bean plant. After the food of the cotyledons has been used up, they wither and fall off. The digestion of stored food material is accomplished by means of ferments or enzymes which are present in the seed. Conditions favorable to germination activate these enzymes. Man propagates many of his useful trees by vegetative reproduc-

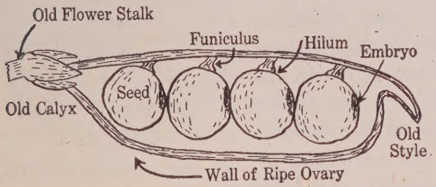


FIG. 74. — Pea pod, a simple fruit.

tion with *slips* and *grafts*. However, the world's supply of seed food is raised from seed.

Fruit. A simple fruit is a ripened ovary with its seeds. The mature wall of the ovary is called the *pericarp*. This may become dry at maturity and split, as in the *pod* of the pea (Fig. 74). The mature fruit of the *lily* is also dry at maturity and is called a *capsule*. Nuts, as the English walnut, are fruits in which the pericarp becomes very hard. A *grain* of corn or wheat (or of any grass) is a fruit in which the seed coats are united with the thin, dry pericarp. In the peach, the outer part of the pericarp is *fleshy* but the inner part forms the *hard pit* inclosing the seed. In the apple (Fig. 75) part of the pericarp forms the *core* while the rest of the pericarp and the receptacle form the fleshy part of the fruit. In the orange (Fig. 76) the ovary is expanded, the *chambers* being filled with juicy *pulp*. Most of the fruits with which we are familiar have had wild ancestors which have been domesticated and greatly improved by plant breeders.

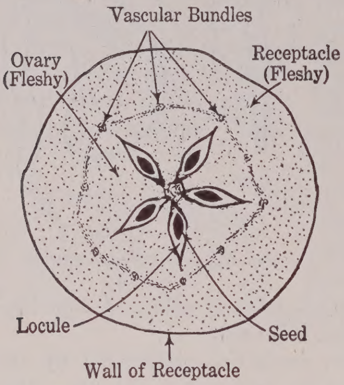


FIG. 75. — Section of apple.

Distribution of Seeds. After the production of seeds, their distribution takes place. Any agency which will scatter seeds and keep them from crowding favors the possibility of developing mature plants. Animals feed on fruits, for example. In the digestive tract of the animal, the fleshy part of the fruit is digested, but many of the seeds are unharmed and pass out with the feces and probably, at places distant from the place where the fruit was obtained. Some seeds have no fleshy coverings. Dry seeds, such as those of *Bidens*, have two prongs with sharp barbs which stick for a time to the hairy coats of animals and so are distributed.

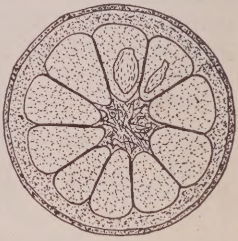


FIG. 76. — Section of orange.

The seed of the dandelion or of the prickly lettuce (Fig. 77) is a veritable parachute. Released from the plant the wind blows these little parachutes hither and thither and the seed is planted far from its place of origin. The seed of the milkweed is somewhat similar in structure. The seed of the maple tree has wings. Nuts contain plant embryos. Certain animals feed on nuts, the embryos of which are destroyed. But the animals using this kind of food gather in supplies of nuts, and in the process of gathering and transportation many drop on the way and thus are distributed. There are also many interesting mechanical devices by which seeds are thrown from the pod.

At this point, it is well to take stock of the principal points of resemblance between the flower and organs of reproduction in lower forms.

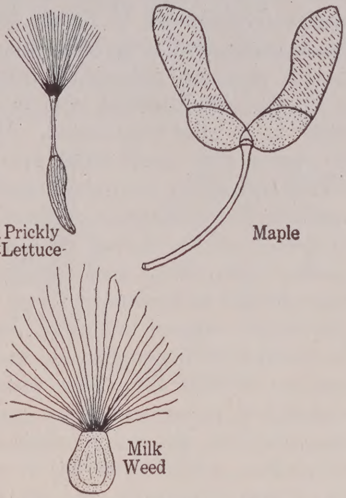


FIG. 77. — Seeds distributed by wind.

Comparison of Reproduction in Angiosperms with that of Lower Forms. 1. The flower of Angiosperms is to be regarded as a specialized strobilus in which the receptacle is homologous with the axis of the strobilus of lower forms and stamens and carpels are sporophylls. Petals and sepals are specialized floral parts.

2. Stamens produce pollen grains or microspores and carpels (pistil) produce megaspores.

3. The pollen tube apparatus is a male gametophyte and the embryo sac is a female gametophyte — and both homologous with gametophytes found in lower forms.

4. The seed contains the embryo which is a new immature sporophyte, while the seed coats are persistent remains of the old sporophyte.

5. Alternation of generations, which occurs for the first time in the Algae, is continued throughout all the remaining plant

groups. The gametophyte becomes reduced to microscopic proportions, while the sporophyte is greatly elaborated.

6. Sexual reproduction insures diversification of zygotes, resulting from the chance union of sex nuclei with different hereditary qualities. Spore production insures distribution through space, since plants cannot move about like animals.

7. The seed with its embryo, food for the embryo and protecting seed coats, is a device to carry the new individual over potentially destructive periods, to reduce infant mortality during the most hazardous period in the life of the new individual and also to transport it to a new environment before it begins its career.

Further consideration is of interest. Spores are very small in order to be wind transported. Many are destroyed, and in order to obviate this, great numbers of spores are produced by plants which still retain the independent gametophyte. In seed plants, spore destruction is greatly reduced, as megaspores, for example, are protected within tissues of the megasporophyll. Phyla which possess independent gametophytes expose the delicate organs of reproduction to destructive forces. In the seed plants, the gametophytes are reduced in size and complexity, so that it is possible for them to be inclosed within the tissues of the sporophyte. The embryo develops for a time within the parent plant until it has established young root, stem and leaf organs. It absorbs food material from the mother plant and stores this in endosperm or cotyledons, available for use at germination. It is protected by tough and waterproof seed coats. Then physiological activities slow down. It is discharged from the mother plant. It still lives, with fires of metabolism dampered. In this dormant state it may survive several unfavorable seasons. When proper conditions arrive, life activities within speed up; growth starts; the embryo bursts its bonds; vigorous roots, leaves, stem and branches rapidly develop.

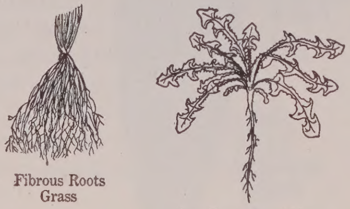
(Selected References at end of Chapter VII)

CHAPTER VI

SPERMATOPHYTA. PART II

MORPHOLOGY OF ROOT, STEM AND LEAF

We have already studied the flower and the reproductive process resulting in the formation of seeds. The seed develops into a plant with three organ systems, namely, the root, stem and leaf. These organs are concerned with the vegetative or metabolic life of the plant.

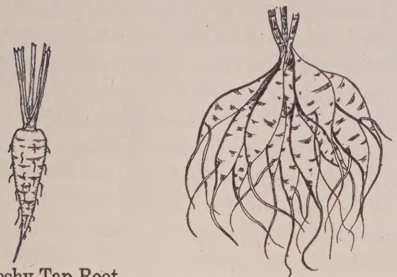

Fibrous Roots
Grass

Tap Root - Dandelion

FIG. 78. — Root types.

A. The Root

Roots usually live in the soil. They anchor the plant, absorb water and mineral salts dissolved in the soil water; they absorb oxygen and give out carbon dioxide. There is a great variety in root form but there are two main types: (*a*) *Fibrous Roots.* Grasses (Fig. 78) have such a root system. There is a thickly branching mass of small roots which grow down from the base of the stem. (*b*) The *Tap Root.* The dandelion (Fig. 78) has one main tap root which grows down into the soil. From this, branch roots develop. Carrots, parsnips (Fig. 79), beets and turnips are examples of thickened or fleshy tap roots, in which sugar and starch are stored. The dahlia (Fig. 79) has a cluster of *multiple roots* at the end of the growing season.


Fleshy Tap Root
Parsnip

Multiple Fleshy Roots
Dahlia

FIG. 79. — Storage roots.

The older parts of roots (tree) are tough and woody, but the very *tip ends* of the smallest roots are soft, delicate structures of vital importance to the plant. Such a *root tip* has five regions which merge into one another. (1) A *root cap* at the very tip. This consists of a covering of cells which protect the tender tissue behind it. As the root tip grows it penetrates between soil particles and in this process the outer cells of the root cap are worn away, but new cells are constantly formed underneath to take the place of the outer cells. (2) Just back of the root cap is the *embryonic region* or meristem. This is a small portion where the cells are undergoing cell division, forming new cells for the root cap and also for the important structure of the root further back. (3) Back of the embryonic region is the *elongation zone*. Here the cells, formed in the embryonic region, grow longer. Thus, increase in length of the root is provided for. (4) A little further back, these lengthening cells are assuming the form they will have when mature. (5) Still slightly further back are cells which *have* assumed this mature form. The accompanying figure (Fig. 80) representing the root tip of a young corn plant illustrates some of the features just named. For a short distance just above the elongation zone in the region of the newly matured cells, some of the epidermal cells develop long, hair-like processes (Fig. 81) called *root hairs*. They are extensions of the epidermal cells. The wall is of soft cellulose and is freely permeable. Just inside the cellulose wall is a thin layer of protoplasm which continues into the epidermal portion of the cell. In the cytoplasm is the nucleus. The cell is not entirely filled with protoplasm but has a large sap cavity. Sap contains sugar and mineral salts in solution. As the root hair develops, it pushes its way out between

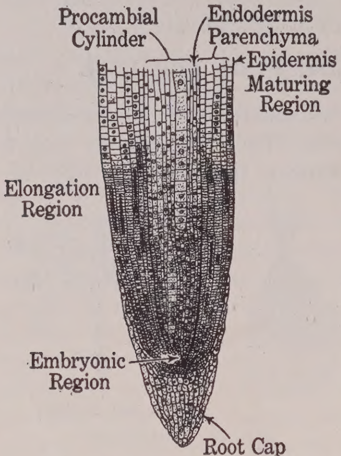


FIG. 80. — Root tip of corn.

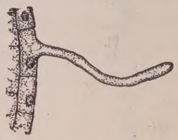


FIG. 81. — Root hair.

the minute soil spaces and comes into intimate contact with soil water. Root hairs do not live very long. As the root tips grow out, new root hairs (Fig. 82) form and the earlier ones, farther away from the tip, die. The surface exposed to soil water is enormously increased by the root hairs. The total area of all the root hairs of a single root tip is many times the area of the surface of the root tip itself. Since there are innumerable root tips in a large tree, the absorbing surface is *so much more* increased by the root-hair device. It is said that *the absorbing surface of all the root hairs roughly approximates the evaporating area of all the leaves.*

Soil fluids cannot penetrate the tough woody bark of old roots. It is the function of these thick roots to anchor the plant, and to make possible added growth in stem, aerial branches and leaves. There is a constant and great increase in numbers of root tips and root hairs. These constitute the only doorways by which water and nitrates and other compounds so essential to the plant can enter.

Root Tissues. Farther back from the root tip, tissues are being organized from embryonic cells which will provide for the annual growth in thickness of the older roots. Let us note stages in this process as may be found in Dicotyledons.

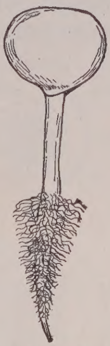


FIG. 82.—Sprouting radish seed showing zone of root hairs.

First. Just back of the root-tip region, an examination of the root reveals a certain amount of tissue differentiation (Fig. 83 *A*). (First) Externally, there is a single layer of epidermal cells, many of which develop root hairs. In the main, the *epidermis* is a protective layer. (Second) Within the epidermis is a zone of parenchyma cells in which starch may be stored. This zone is called the *cortex.* (Third) Within the cortex is the *central cylinder* or *stele,* which is separated from the cortex by a single layer of cells called the *endodermis.* Just within the endodermis (fourth) we find four (for example) *alternating* masses of *xylem* and *phloem. Xylem* consists of large, thick-walled, woody cells, giving rigidity to the root. Its cells form long ducts in which soil fluids are carried from roots to stem and leaves. Alternating with the four *xylem bundles* are four *phloem bundles.* Phloem consists of thin-walled special cells which transport sugar solutions from leaves, down through the stem to all the roots. Additional xylem cells forming centrally result in a four-pointed xylem mass. (Fifth) Between these primary xylem and primary phloem masses are groups of cells resembling those of the embryonic region in the tip. These cells also retain the *power of cell division,* and the tissue which they constitute is called *cambium.*

A branch rootlet may grow out from such a young root. If so, it arises from the cambium in the stele and grows out through the cortex and epidermis.

Second. Having studied the early histology, let us note the structure of this region later in the growing season, *i.e.,* Fig. 83 *B.* Epidermis, cortex, endodermis are shown as before. It should be stated that within the endodermis is tissue similar to that of the cortex, *i.e.,* parenchyma. The four separate masses of cambium have extended toward each other with the result that there is a complete cambium cylinder, though it is not yet exactly circular in cross-section. Added xylem, now called *secondary xylem,* is formed from the inside of the cambium and built upon the outer face of the first formed and centrally located, *primary xylem.* Wider masses of phloem have formed from the outer face of the cambium. The first four masses of phloem, *i.e., primary phloem,* are pushed out further.

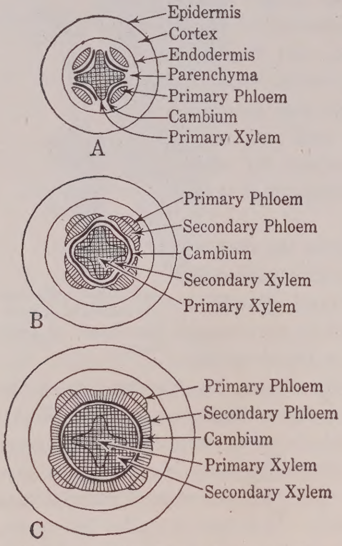

Epidermis
Cortex
Endodermis
Parenchyma
Primary Phloem
Cambium
Primary Xylem
A
Primary Phloem
Secondary Phloem
Cambium
Secondary Xylem
Primary Xylem
B
Primary Phloem
Secondary Phloem
Cambium
Primary Xylem
Secondary Xylem
C

Fig. 83. — Histology of young root.

Third (Fig. 83 *C*). Now let us study the same portion of the root toward the end of the year's growth. Around the central mass of primary xylem is a still larger mass of secondary xylem. The cambium is even larger in circumference. Outside the cambium is a complete and wider *ring* of secondary phloem. The last xylem cells formed toward the end of the summer are small. When growth is resumed the next spring, large xylem cells are formed from the inside cambium cells. Later on, the xylem cells are smaller. The contrast between smaller xylem cells of late summer and adjacent large xylem cells of the next spring gives the appearance of a succession of ' rings ' of xylem or *wood.* Of course, new phloem is formed from the outside of the cambium. The older phloem is gradually pushed out toward the periphery of the ever-thickening root. Certain cells of the parenchyma inside the endodermis and later certain cells of the older phloem will form a cork which makes the ' bark ' of the root waterproof.

We have spoken of the cambium as a ring. But the diagram shows only a cross-section of the cambium. In reality it is a cylinder, as are also the secondary xylem and the phloem. The reason the cambium remains about the same thickness year after year can now be explained.

Cambium cells (Fig. 84) are roughly rectangular in shape. The cambium cell C divides, as shown in the figure, into two small cells, c and xy. When formed, c grows into another cambium cell, C, while xy develops into a xylem cell, XY, on the *outside* of an older xylem cell. But elsewhere in the cambium, a cell C has divided into two cells, c and ph. The cell c develops into a cambium cell again, while ph develops into a phloem cell, PH, which is just *inside* the old phloem but on the outer side of the cambium. Any cambium cell may develop now a xylem cell and cambium cell, and the latter cambium cell may next produce a phloem cell and another cambium cell. The constant formation of new xylem and phloem increases the thickness of the stem, but the thickness of the cambium layer remains about the same. At the end of the second season we find two rings of woody xylem within the enlarged cambium cylinder. There are also two rings of phloem outside. It is evident that before long the old cortex and epidermis will be effaced. Moreover, due to the pressure of the earth, the outer (phloem) tissues are rubbed off. Old phloem decays quickly, so that roots never have very thick *bark.*

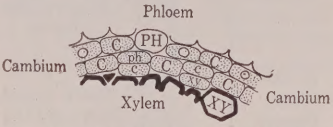


FIG. 84. — Cambium cells forming xylem and phloem cells. (Diagrammatic.)

B. The Stem

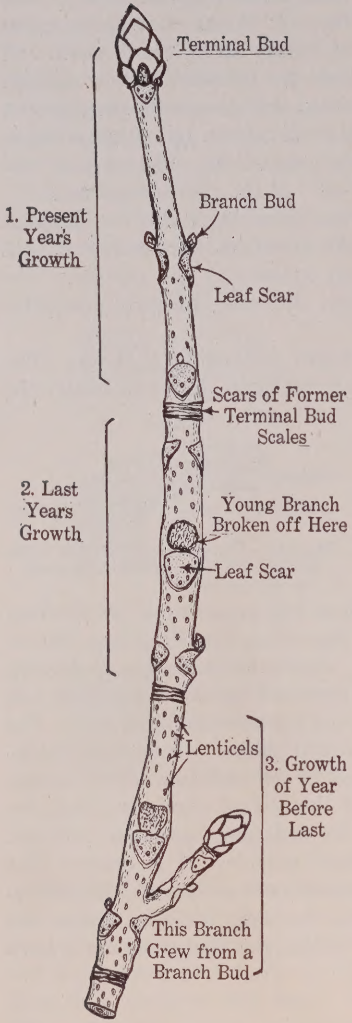

Terminal Bud
1. Present Year's Growth
Branch Bud
Leaf Scar
Scars of Former Terminal Bud Scales
2. Last Years Growth
Young Branch Broken off Here
Leaf Scar
Lenticels
3. Growth of Year Before Last
This Branch Grew from a Branch Bud

FIG. 85. — Horse-chestnut twig in autumn.

Materials are conducted from the roots to the leaves through the stem, and substances pass from the leaves through the stem to all parts of the plant. The number of leaves is increased to a great extent by the branching habit of the stem. There is a great variety in the form and structure of stems.

A Young Dicotyledon Stem. Fig. 85 is a diagram of the end portion of a *branch* of a horse-chestnut tree taken in autumn after the leaves have fallen. The terminal portion is that part formed during the current summer; the middle portion is two years old and the remaining part is three years old. At the tip end is the terminal bud. Back of it are seen shield-shaped *leaf scars*, indicating places of attachment of former leaves. Just above the scar is a *branch bud.* When the leaf was alive, the branch bud was in between the branch and the leaf petiole, that is, in the *axil* of the leaf. At the junction of the terminal and middle segments are seen scars about the branch. These were left when the bud scales of the terminal bud fell off in the spring of that year. Just back of the middle growth are similar scars marking the position of the terminal bud in the spring of the preceding year. Farther back, due to the growth of the stem in diameter, these indications of the yearly increments in length disappear.[1] The length of the internodes varies from year to year. There may be several reasons for this. One season must have been more favorable for growth than another.

The structure of the tip of a stem is similar in some respects to that of a root tip. There is no root cap, of course, but there is an embryonic region or *meristem* tissue where *cells divide* — thus providing for added growth. Back of these dividing cells is a zone of *elongation, i.e.*, where cells are elongating and assuming their permanent form; farther back is a region where the cells have assumed their permanent length and the stem increases no farther in *length* at that point, but there is an increase in *diameter* from season to season. There is no sharp line of demarcation between these zones.

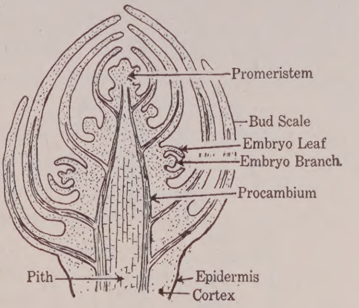


FIG. 86. — Vertical section through a terminal bud.

Buds. At the tip of every branch will be found a bud (Fig. 86) protected by scale leaves. Inside of these at the very tip is a small area of promeristem tissue, where cells retain the power of cell division. Adjacent or lateral to this are a number of other embryonic regions. They will develop stem and leaf structures and also flowers.

Stem Formation. The buds are dormant during the winter, but with the return of spring, activities become renewed. There are at least four types of activities:

1. *Cell division* in the meristem region. This will continue all through the summer. 2. *Elongation* of this portion of the stem due to the lengthening of some cells formed by division. 3. *Differentiation* of early similar cells into various tissues which when formed exhibit no further change. 4. Increase in *diameter* of the stem.

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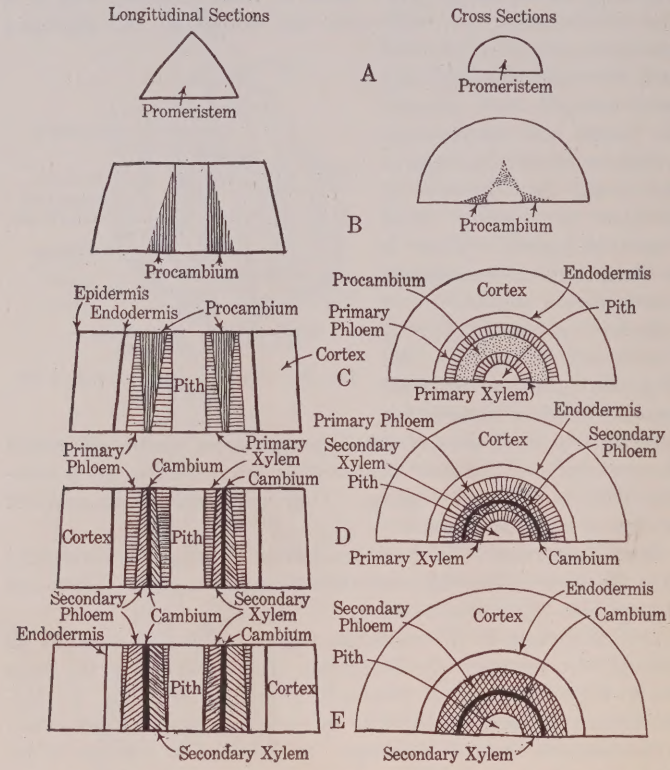
[1] In a casual examination of a certain horse-chestnut tree, one branch showed twenty annual increments of growth by the scars of old terminal bud scales.

These changes take place as the season advances. We may obtain an idea of what occurred during the season by studying sections taken at various levels of the terminal portion of a dicotyledon stem. Only a general account can be presented here (Fig. 87).

1. The tip of the stem is a region of homogeneous tissue where the cells are small, of equal size throughout and undergoing cell division in any plane. This is *promeristem* tissue (Fig. 87 *A*).

2. Behind this — or among older promeristem cells — some become slightly elongated and more densely packed with protoplasm.


Longitudinal Sections
Cross Sections
A
Promeristem
Promeristem
B
Procambium
Procambium
Epidermis
Endodermis
Procambium
Pith
Cortex
Primary Phloem
Cambium
Primary Xylem
Cambium
Procambium
Primary Phloem
Cortex
Endodermis
Pith
C
Primary Xylem
Cortex
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Secondary Phloem
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Cortex
Endodermis
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D
Primary Xylem
Cambium
Pith
Cortex
Secondary Xylem
Secondary Phloem
Pith
Cortex
Endodermis
Cambium
E
Secondary Xylem

Fig. 87. — Histology of young dicotyledon stem. *A*, *B*, *C*, *D*, *E*-sections at different levels from the tip; longitudinal sections at left and half cross-sections at the right. Modified from Eames and MacDaniels' *Introduction to Plant Anatomy*, copyright 1925, McGraw-Hill Book Co., reprinted by permission.

These form in groups at regular distances from the center, as shown in diagram, Fig. 87 *B*, which shows the sections of these elongated cells, now called the *procambium.* The clear space is occupied by the promeristem cells.

3. Now the procambium cells at the *inner borders* of the procambium strands, *toward the center,* differentiate into *primary xylem* cells (Fig. 87 *C*). The procambial cells at the *outer border* of the strands, *i.e., toward the surface,* differentiate into *primary phloem* cells.

4. New procambial cells are added to the procambial strands by *differentiation* of promeristem cells, so that an entire ring of procambium is formed. It is really a hollow cylinder (Fig. 87 *C*), considering all three dimensions of the stem. The student should remember that when the word *ring* is used, he should visualize this as a sectional view of a hollow cylinder. In different stems, varying numbers of strands are formed; in some cases the entire ring may appear at once.

5. As the extension of the procambium to form a complete ring continues, the differentiation from procambium to *new xylem* and *new phloem* occurs also, so that three rings now appear: an inner ring of xylem, middle ring of procambium, outer ring of phloem (Fig. 87 *C*).

6. The promeristem cells inside the procambium and its primary xylem now gradually differentiate into *pith,* while those outside the procambium and the primary phloem have become *cortex* covered with one layer of cells, the *epidermis.*

7. The formation of the primary xylem and primary phloem has been at the expense of the procambium. This is finally reduced to a thin layer between the wide primary xylem and phloem (Fig. 87 *D*). The few remaining procambium cells of this layer no longer differentiate directly into xylem and phloem, but remain as *cambium,* and retain the power of cell division by which they will split off cells *within,* to become *secondary xylem,* and split off cells *without* to form *secondary phloem.*

8. At the end of the season (Fig. 87 *E*) the *oldest* portion of the current year's growth of the stem would show:

1. Pith in the center.
2. Vascular cylinder.
    - (*a*) Xylem ring inside — thick.
    - (*b*) Cambium ring between — thin.
    - (*c*) Phloem ring outside — thick.

   (*d*) Parenchyma tissue.
   (*e*) Endodermis.
3. Cortex.
4. Epidermis.

A Study of the Structure of the Two-Year-Old Stem (Fig. 88). The stem remains dormant during the winter. The last xylem cells formed in summer are small and rigid. Now with the spring awakening, the cambium forms large *water-conducting* xylem cells for a time. But as the season advances it forms the narrower, more rigid cells. Of course, cambium also forms phloem cells outside, *i.e.*, on the inner side of old phloem cells, pushing out the latter. The contrast between the small summer xylem cells of one season and the large spring xylem cells of the next season gives the appearance of concentric rings of wood. And in general, the number of wood rings seen in cross-section indicates the age of the tree. These are not always of equal width, which indicates variations in the nature of the seasons, some being favorable to growth, others not. A season of drought in midsummer followed by a warm, wet, late summer might cause two rings to be laid down. Photomicrographs of sections of one-year, two-year and three-year-old linden stems are shown in Fig. 89.

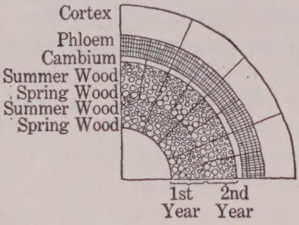

FIG. 88. — Diagram of section of stem two years old.

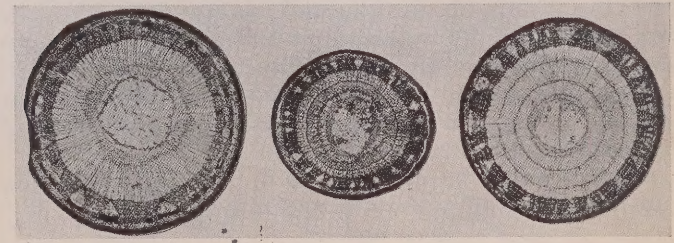

FIG. 89. — Photomicrographs of (left) one-year; (middle) two-year; and (right) three-year-old linden stems. One, two, and three rings of wood (xylem) can be seen. Radiating lines are sections of vascular rays. Phloem is thick dark band outside xylem, and cambium between phloem and adjacent xylem. Triangular-shaped masses in phloem ring are expanded masses of vascular rays with phloem between them. Pith is in center of stem.

Tissues of a Woody Stem. *Epidermis.* This is a single layer of cells protective in nature. The cells may contain chloroplasts and starch may be made. Special cells guard the stomata or air pores. Later the epidermis disappears.

Cortex. This is a zone of parenchyma cells underneath the epidermis. It is later crushed by the increasing phloem inside. Moreover in some stems the epidermal cells or some of the outer cortical cells develop into a special meristem, called the cork cambium. This forms waterproof *corky* cells outside and a few parenchyma-like cells inside of it. Portions outside this cork cambium dry, shrivel up and peel off as seen on the trunk of the cherry or birch. New bark of this sort is constantly formed. In other trees the cork cambium continues to form deeper into the cortex and splits off pieces of 'bark,' and invades the old dead phloem. Thus there is no cortex in older branches, and since pieces are constantly falling off, the bark does not seem to increase in thickness. In many trees as the corky bark replaces epidermis, the cork cambium forms masses of cells *loosely arranged* near old stomata, thus leaving an air passage to the inner tissues. These are called *lenticels* and are characteristic of smooth bark trees like the cherry and birches. (See Fig. 85.)

Phloem. Inside the cortex is the phloem. This consists of sieve tubes (Fig. 90), special cells for the conduction of proteins, fats and carbohydrates in solution down the stem. The ends and lateral walls of these cells are sieve-like. Alongside them are companion cells with cytoplasm and a nucleus. They are thought to control the activity of the sieve tubes. Phloem also contains fibers and phloem parenchyma cells.

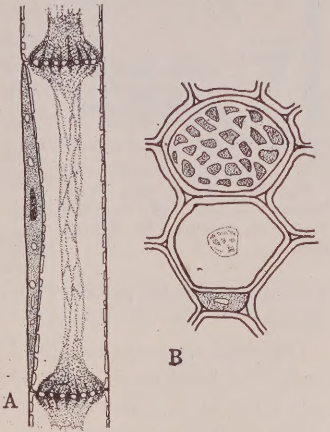

FIG. 90. — *A.* Side view of a sieve tube with slender companion cell on the left. *B.* Sectional view of sieve-tube end (above); through middle of another sieve tube and its companion cell (below). From Sinott, *Botany*, McGraw-Hill Book Co., reprinted by permission.

Cambium. The activity of the cambium has been explained in our study of the root. Cell division in promeristem can take place in any plane. In cambium it is restricted.

Xylem is inside the cambium. It is known as wood. In general it is supporting tissue, but also conducts soil water up the stem. The cell walls of cellulose become hard and rigid, *i.e.*, lignified. Various cells are formed in this tissue (Fig. 91). *First.* Long, slender, thick-walled cells with almost no cavity, becoming wood fibers adapted for rigidity. *Second.* Long wood parenchyma cells. *Third.* Tracheids are long cells whose walls are lignified and pitted. Pits are thin places through which fluids can easily diffuse. *Fourth.* Vessels, the chief water-conducting elements of higher woody stems. Some are short, wide cylinders with lignified pitted walls; drum-shaped and fitted end to end to form long ducts for passage of water. Both tracheids and vessel elements die when mature.

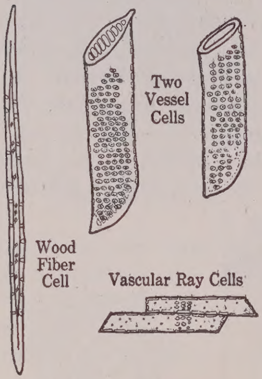

FIG. 91.—Xylem cells. From Sinnott, *Botany*, McGraw-Hill Book Co., reprinted by permission.

Vascular (*wood*) *Rays* (Fig. 91). The cambium also forms vertical and radiating plates of living cells which connect xylem with the phloem, making possible lateral transfer of plant fluids in and out. These have often been called medullary rays, but are now known as vascular rays. They give " quartered oak " its peculiar quality.

Old wood rings are usually dead and do not conduct water and are called *heart wood.* The newer xylem that transports water is called *sap wood.* The number of xylem rings composing sap wood varies in different stems.

Spring wood consists chiefly of water-conducting vessels, while *summer wood* consists chiefly of the more rigid and strengthening elements of wood, such as the fibers.

Monocotyledon Stem. The above account of root and stem structure, involving a cylinder of cambium and annual "rings" of xylem and phloem, applies to Dicotyledons. The stem of Monocotyledons has a different structure. In the stem of the corn (Fig. 92) there is an outer epidermis, while parenchyma is the ground substance in which are found *scattered* vascular bundles. When examined, *each bundle* (Fig. 93) is seen to consist of a ring of bundle-sheath cells, more numerous toward the peripheral and central borders of the bundle. The xylem consists of a *few large* cells just peripheral to the central bundle-sheath cells. One xylem cell lies in a large space. External to the xylem cells is the phloem composed of sieve tubes and companion cells. Parenchyma cells are also present. Most perennial forms such as the palm and bamboo have no provision for increase in thickness of stem except by the delayed maturing of early formed cells. The principal growth is apical, thus forming long, slender trunks as that of the bamboo.

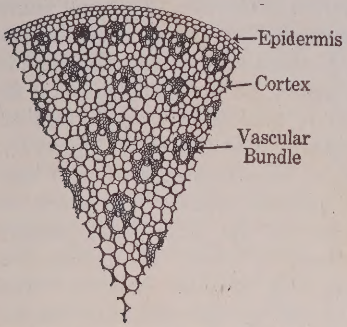

FIG. 92. — Portion of cross-section of corn stem.

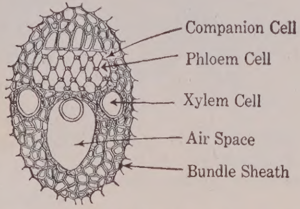

FIG. 93. — Vascular bundle of corn stem.

C. The Leaf

Woody trunks with their extensive branching habit expose a great mass of leaves to the sunlight. Gager has given us a most profound statement concerning the importance of the leaf. "There is no more important fact in botany," he says, "nor indeed in all natural science, than that all the food of the world is primarily manufactured in the chlorophyll-containing cells of the leaf." Someone has estimated that an elm tree of average size possesses about 7,000,000 leaves with a total surface of about five acres, over four hundred times the area of ground occupied by the tree. The leaf habit, first clearly indicated in

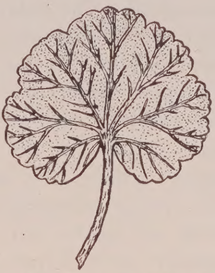

FIG. 94 *A*. — Geranium leaf. At end of leaf stalk or *petiole* is undivided *blade*.

Pteridophytes, is carried to a climax in the great leafy expanse exhibited by trees. A typical leaf has a flat, thin *blade*, where work of vital importance to the plant is carried on. This is supported by a small stem-like structure called the *petiole*. There is great variation in the size, shape and many other characteristics of leaves. For example (Fig. 94 *A*), there may be one single blade in *simple* leaves, or the blade may be divided into a number of small leaflets. Such leaves are called *compound* (Fig. 94 *B*). The leaves of Monocotyledons (corn) usually have parallel veins. The leaves of Dicotyledons, on the other hand, usually have a network of veins. The petiole is a small stem with vascular bundles. The veins of the leaf are also miniature continuations of stem structure ramifying throughout the leaf, carrying vascular or circulating tissue out to the leaf cells.

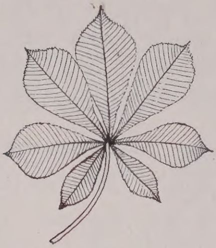

FIG. 94 *B*. — Horse-chestnut leaf. At end of petiole is divided blade.

Figure 95 shows the structure of the leaf. On the upper surface is a row of protective epidermal cells. The lower surface of the leaf is also protected by another layer of similar epidermis. There is no chlorophyll in most cells of the epidermis. Between the two epidermal layers is the *mesophyll*. The cells here are divided into two regions. In the first place, there is a layer of long cells at right angles to the upper surface, the *palisade parenchyma*. Beneath these cells is the *spongy parenchyma*, where the cells are arranged irregularly with air spaces here and there. The cells of the palisade and spongy parenchyma contain chlorophyll bodies. Palisade and spongy parenchyma form the mesophyll. It is in the mesophyll that starch is made.

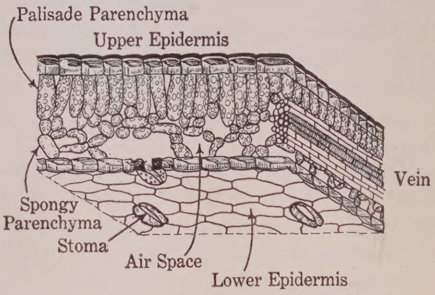

FIG. 95. — Histology of leaf. From Sinnott, *Botany*, Revised Edition, McGraw-Hill Book Co., reprinted by permission.

In the *lower epidermis* are air pores. These are called *stomata*, through which gases can pass in and out and through which water vapor escapes. Each stoma (Fig. 96) is a slit between two special, somewhat crescent-shaped epidermal cells called *guard cells.* Unlike the ordinary epidermal cells, they contain chlorophyll bodies. Scattered in the mesophyll are veins, each being a vascular bundle. Each vein is surrounded by a bundle sheath inclosing xylem and phloem cells. The very smallest veins possess but one or two ducts composed of these cells. The epidermis is coated with a non-cellular, waterproof layer called *cuticle.* This is thicker in some leaves than in others. It has been claimed that the difference in thickness of leaves is due chiefly to the variations in thickness of epidermis and not of the mesophyll, which in all leaves is more constant.

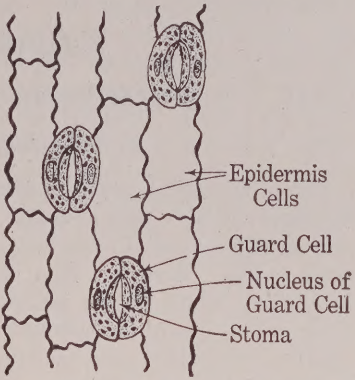

Fig. 96. — Stomata of leaf.

(Selected References at end of Chapter VII.)

CHAPTER VII

SPERMATOPHYTA. PART III

A. Physiology of Plants

The physiological processes necessary for life are, on the whole, the same in plants as in animals. No matter how simple or complex an organism is, it must carry on certain kinds of activities in order to live. There are three classes of these functions. First, *Metabolism*, which is the totality of chemical processes which occur in protoplasm and involves processes such as digestion, circulation, respiration and excretion. Second, *Adaptation*, or adjustment to the environment. Third, *Reproduction*, which is not exactly necessary for the life of the individual organism, but is essential to the continuance of the species. Plants differ from animals in that many of them can manufacture food from inorganic materials, while animals depend on organic materials for food. We have already considered reproduction in plants, and therefore in this section we will take up only metabolism and adaptation. We will first study metabolic functions.

Photosynthesis is the process by which starch is made in the green leaf from carbon dioxide and water. Carbon dioxide is taken into the leaf through the stomata. It enters the air passages and is taken up by the mesophyll. Water is delivered to these cells by the xylem tissue of the veins. We do not know *exactly* what happens. If we did, there would be factories in which starches would be made from carbon dioxide and water. However, we know something about the process.

To accomplish this manufacture in the leaf, energy is necessary. This is furnished by the sunlight and it is apparently the red and violet rays of sunlight that are mostly used. These are absorbed by the chlorophyll, and this, or something in it, is the agent which enables the change to take place. The unabsorbed rays of sunlight passing through chlorophyll give a green sensation to the eye. Chlorophyll is soluble in alcohol, ether and chloroform. However, such solutions of it are ineffective as starch formers. Apparently the carbon dioxide and water are split into their component parts and then recombined. The formation of starch probably occurs in a series of steps. One suggestion is that carbon dioxide and water unite to form carbonic acid gas, H_2CO_3. An enzyme splits off oxygen from this, making formic acid (HCOOH) and oxygen. Then another enzyme splits off more oxygen, making formaldehyde (HCOH) and oxygen. Later molecules of formaldehyde synthesize to form glucose, a simple sugar, ($C_6H_{12}O_6$). The amount of glucose formed increases in sunlight and decreases in the dark. There is a certain optimum intensity of light at which it takes place most rapidly. This means that too intensive light is not favorable. It is not formed in the dark. There is also an optimum temperature. With the increase in the carbon dioxide up to a certain point, there is also an increased production of sugar. As fast as the leaf makes sugar, it is converted into starch, and this is stored in the cells of the leaf. During the night the excess starch stored in the leaf is reconverted to sugar, passed down conducting tissues and may be converted into starch elsewhere; possibly stored in an underground stem, as in the potato. A square meter of leaf surface makes about ten grams of starch per day or three pounds per summer. It takes over a thousand liters of carbon dioxide to do this. After chlorophyll has been extracted from green leaves, they are white, and if starch is present, they will turn blue in iodine solution. Plants grown in an atmosphere devoid of CO_2 do not make starch. Van Helmont, a Flemish scientist of the early seventeenth century and one of the founders of physiological chemistry, planted a willow tree in a certain quantity of dry soil. He added nothing but water to the soil. At the end of five years growth, both tree and soil were weighed. The tree had increased greatly in weight but the weight of the soil remained about the same. From this Van Helmont concluded that materials for growth were furnished by the water he had added. This of course was only *partly* correct. It is interesting to note that he also observed that when wood was burned, part of its substance was dissipated in the form of what he called the " spirit of the wood " or what we would call a gas, and what we now know to be carbon dioxide. Van Helmont did not ascertain the rôle of atmospheric carbon dioxide in the growth of his willow tree. Photosynthesis stores energy, for by it a supply of energy-yielding material is manufactured. The sugar (or starch) thus made is essential for the formation of new protoplasm, new cells, *i.e.*, growth.

Plastids. An important group of cytoplasmic bodies called *Plastids* are characteristic of plant cells. There are three principal types. (*A*) *Chromoplasts* are present in colored floral leaves and in fruits. They are little bodies which contain pigments imparting the color to the petals or to fruits such as the apple and tomato. (*B*) *Leucoplasts* are white or gray, unpigmented bodies around which starch grains form from sugar solution in the cells of storage tissues. (*C*) *Chloroplasts* are of particular interest to any understanding of the biology of the green leaf. They are very small porous bodies covered with fine particles of chlorophyll in suspension. It can readily be seen that a much greater surface of chlorophyll exposed to sunlight is attained by the presence of many small particles covered with chlorophyll than if the cell contained one large body thus covered. There are said to be two types of chlorophyll pigments, each with a definite function. Other pigments are associated with those of chlorophyll. For example, *xanthophyll* is pale yellow, while *carotin* is rather orange in color. Both xanthophyll and carotin may be present in the chromoplasts of flowers and fruits. They cannot, however, perform the function of photosynthesis. Chlorophyll is needed for this. Harvey found that photosynthesis occurs in plants illuminated with light from nitrogen-filled tungsten electric lamps. Chlorophyll is constantly being made and constantly destroyed. It functions in solutions containing proper compounds of C, O, H, N and Mn. Iron must also be present. Chlorophyll apparently absorbs light rays, for the most part, from the red and from the violet end of the spectrum. It is believed that the energy furnished by these light rays is converted by the chlorophyll into energy which is used in photosynthesis. About 20% of the total energy of the light is stored in the products of photosynthesis. Some plant cells contain red or blue pigments dissolved in the cell sap. These are known as *anthocyans* and are present, for example, in red onions or in red and blue flowers.

During the summer, chlorophyll is destroyed about as rapidly as it is made. In the autumn, its manufacture gradually ceases and so the leaves are no longer green. Xanthophyll and carotin pigments now reveal themselves in the color of the autumn foliage.

Or, possibly, the nights have been frosty and such a condition favors the accumulation of sugars and anthocyans and so the red leaves of maples, oaks and sumachs are prominent. The browns and blacks are merely the colors of dead cellulose walls and the various shades of color seen in autumn leaves are varying compositions of these with the cell pigments.

Respiration. Oxygen is necessary for animal and plant life. Oxidation is the keystone of the many processes of metabolism. Carbon dioxide and water are the by-products of oxidation. Plants *take in* oxygen chiefly through the stomata of the leaf and also through the stem and roots. This is one phase of respiration. The waste products of oxidation are carbon dioxide and water, which are eliminated chiefly through the stomata. This is the other phase of respiration. Respiration occurs in all plants and animals. Photosynthesis takes place only where there is chlorophyll; respiration takes place in all living cells of plants and animals. Photosynthesis occurs only in the light; respiration continues through the night and day. Photosynthesis manufactures food; respiration occurs where oxidation burns up food. In photosynthesis, carbon dioxide is absorbed and oxygen is a by-product; the reverse is true in respiration. Photosynthesis stores energy; respiration accompanies the release of it.

Transpiration. Water, which is a by-product of photosynthesis, collects in the air spaces of the leaf in the form of water vapor. From these spaces it passes out through the stomata into the atmosphere. Light, warmth, dry air and wind increase this movement of water. Some of the water (the greater part of it) has arrived in the leaf, via the conducting vessels of the veins and stem. Removal of it by transpiration makes possible a further movement of liquids up from the earth. Besides external conditions favorable to photosynthesis, a brisk movement of water to the leaf is essential. If transpiration exceeds absorption, the plant wilts. In transplanting, care should be taken not to destroy root hairs. The root system should be disturbed as little as possible. Moreover, after re-planting, the leaf area should be reduced, the plant should be covered and water added around the roots in order that absorption shall be greater than transpiration. Water loss in the cactus is greatly reduced by the reduction of transpiration area to that of the surface of the stem, for the leaves are represented by spines. In the rubber plant, stomata are at the bottom of pits. On the under surface of some leaves, hairs are present, thus restricting the free play of air currents about the stomata.

Transfer of Water and Mineral Salts. Water and solutions of mineral salts rise to the tops of the tallest trees. A great number of long ducts of extremely minute diameter traverse the plant. Through these water and mineral salts, dissolved in the water, pass from the earth to all parts of the plant. Just what forces are responsible for this movement of fluids, we do not exactly know. The cause is probably the resultant of a number of forces. Mesophyll cells of leaves secrete a solution on their outer surface. This becomes concentrated by evaporation, which causes more water to be drawn from the interior of the cells and these in turn absorb more water from the veins and aid the rise of sap. Osmotic pressure of the sap is greater in more elevated cells as compared with cells at lower levels, and this would tend to create an upward passage of water from cell to cell. Then again, capillarity would explain a partial rise of liquid in these tubes. Transpiration or removal of water from the upper end of the system of ducts would also aid its movement upward. The *very minute diameter of the ducts*, which thus present a relatively large surface area in proportion to the inclosed fluids, is probably an essential part of the mechanism. Capillary attraction would serve to support the very small weight of water at any one point. Variation in osmotic pressure, transpiration, avoidance of a vacuum and pressure from below would make for a movement of fluids. Transpiration alone does not account for the ascent of fluids in stems. When some stems are cut off near the ground, water oozes out of the cut surface of the rooted portion. The cut end may be connected with a mercury manometer and it is found that the "root pressure" raises the column of mercury over the pressure of the atmosphere. This indicates a positive force, apart from the phenomena occurring in the leaves.

Protein, Carbohydrate and Fat Manufacture. From the sugar made in their leaves and from compounds of N, C, H, O, K, Fe, S, P, etc., plant cells can make more protoplasm. This is a process of synthesis of proteins. Certain compound proteins are characteristic of certain seeds; for example, gluten of wheat flour, and zein of corn. Plant proteins are markedly present in peas, beans and lentils, also.

Some of the carbohydrate made, is stored not as starch but is changed to fat. This is true of the olive and the seed of flax (linseed oil), cotton, and also other seeds, usually called *nuts*, such as the peanut. Glucose is soluble in water, but starch and fat are not, and so glucose is converted to starch or fat for storage. The energy that is stored is valuable as well as the carbon, hydrogen and oxygen. Cane sugar ($C_{12}H_{22}O_{11}$) is stored in such plants as the sugar beet and sugar cane. Much of the glucose made by plants is converted into cellulose and forms the wood and bark of trees; the fibers of the flax stem from which linen is produced and the fibers of cotton, associated with the cotton seed. The word *assimilation* refers to the building up or formation of more protoplasm from proteins, fats, carbohydrates and mineral salts.

Enzymes are protein-like compounds that hasten the speed of chemical reactions. Many enzymes are found in plant tissue, and life processes are fundamentally dependent upon the presence of these enzymes. Enzymes are produced by the living cells.

Hydrolyzing enzymes add water and split molecules. Thus, cane sugar is made into glucose and fructose[1] ($C_{12}H_{22}O_{11} + H_2O) = 2(C_6H_{12}O_6)$. Such enzymes are *hydrolases. Monosaccharids, disaccharids, polysaccharids,* are converted from one to the other by means of enzymes. By *dehydration synthesis,* glucose and fructose are made into cane sugar with the loss of water, thus

$$2(C_6H_{12}O_6) - H_2O = C_{12}H_{22}O_{11}.$$

Lipases act on fats and oils, changing them into fatty acids and glycerine, in which form they may be transported. Other enzymes change carbohydrates into fat and fat into carbohydrates.

Proteases convert complicated proteins into amino-acids. The building up of complex proteins and protoplasm itself involves the presence of special enzymes.

Fermenting enzymes change sugar to alcohol. Probably all chemical life processes involve enzymes.

The photosynthetic manufacture of starch by enzymes has been described in terms of enzymes as follows: First: An *oxidase* changes water and carbon dioxide to formaldehyde; *aldehydase* changes formaldehyde to glucose; a *maltase* changes glucose to maltose; a *dextrinase* changes maltose to dextrine; an *amylase* changes dextrine to amylum, a soluble starch; and finally *coagulase* changes amylum to insoluble starch. Some investigators, on the other hand, deny that chlorophyll action is fundamentally enzymatic.

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[1] Glucose and fructose have the same chemical formula, *i.e.*, $C_6H_{12}O_6$, but not the same atomic arrangement in the molecule.

Digestion and Secretion. *Digestion* is just as necessary a process in plants as animals. It means the changing of an insoluble food into a soluble form. Digestion takes place in a fluid medium. We have seen that the green leaf stores some of the manufactured carbohydrate for a time. If this storage process continued, a condition would soon result whereby the normal functioning of the leaf would cease. When night comes, further starch formation ceases. Enzymes *secreted* in the cells digest the starch to a simple sugar which is transported to other parts of the plant. For example, new root-tip cells are forming. They absorb some of this sugar and so obtain part of the material needed to make the requisite amount of new protoplasm they will possess when mature. Protoplasm is everywhere disintegrating. More supplies are needed for repair. So digestion constantly goes on, rendering storage starch available for living cells. The starch of a potato is digested for the use of the new potato plant and that of the wheat grain, for the use of the new wheat plant. Similarly proteins and fats are also digested in plant cells; the gluten of the wheat grain is made available as amino-acids for the young wheat plant and the oil in the peanut for the young peanut plant. Secretion of enzymes is involved in these processes.

Oxidation has been referred to in our discussion of respiration. Oxidation simply defined is the combustion of carbon compounds by oxygen, liberating energy and forming, as by-products, CO_2 and H_2O. Life is a series of complex chemical reactions. Energy utilization characterizes many of these reactions. It is evident in such fundamental processes as cell division and growth. Metabolism is sometimes thought of as being composed of two series of reactions. The first set, leading up to the formation of protoplasm, is known as *anabolism;* the second set, disintegrating processes, *katabolism.* Oxidation is a katabolic process. Glucose, $C_6H_{12}O_6$, is a common product of photosynthesis. Its formation results in the transformation of kinetic energy into potential energy. The oxidation of one gram of glucose releases four calories of heat energy and forms the compounds, CO_2 and H_2O. Oxidation of glucose in plant and animal cells is brought about by means of enzymes called oxidases, which operate at ordinary temperatures.

Excretion. As a result of katabolism, chemical compounds are formed which are of no use to the organism. In fact, their presence hinders cell functions. So they are discharged from the cell and eventually from the organism. Such substances are called excretions. Water and carbon dioxide leaving the plant are two of the principal excretory products. The formation of cellulose, wood and bark and of such substances as resins, gums, perfumes, nectar and even poisons are other examples. Excretions are often confused with secretions. The reason for this is that there is no common single word to express the facts exactly. Possibly the best that can be said is this: the *process* by which cells *make products* to be *discharged* from them is called *secretion*, as, for example, the secretion of resins, gums or enzymes. If the product is to be employed in some further physiological activity, it is called a secretion (*noun*) as, for example, an enzyme; but if it is of no further use — but is, as far as the plant is concerned, waste matter, — it is then called an *excretion*, as, for example, carbon dioxide and the gums and resins. Plants accumulate wastes in the wood and bark, formed season after season. Only a small part of an enormous tree is really alive. This includes the growing points of stem and roots, the cambium and a few cells adjacent to this and many cells of the leaves.

Growth is a physiological process involving cell division, the attainment of mature size and special form and function of the new cells. It involves the formation of more protôplasm, more plastids, the retention of more cell sap and the laying down of more non-protoplasmic structures such as cellulose walls; it results in a further extension of the root, stem and leaf system. Someone once contrasted the growth of crystals with that of organisms. Crystals grow by accretion, *i.e.*, the addition of similar material to the faces of the crystal. Living organisms grow by intussusception, *i.e.*, growth from within. But growth in organisms is not formless, aimless, indefinite. It occurs by the formation of new and specialized cells and the formation within them of more nuclear matter and more cytoplasm and the deposition between them of more non-living matter such as cellulose in plant cells or bone in certain types of animal cells. Usually the sum total of all these processes expresses itself in increased size. When we plant a potato or onion, we soon see a green plant above the ground. *For a time*, the compounds forming the living material of the young plant are derived from the potato or onion planted. The potato itself decreases in size as a result, but the new plant increases in size. It is a matter of transfer of materials although other vital processes are at work as well. The germination of the seed involves growth. After young plants attain physiological independence, they convert inorganic materials into protoplasm for *further growth*. Plants do not store nutriment in seeds for the use of man. The food is stored there for the use of the embryo plant to be utilized at the time of germination. Growth involves the formation of more protoplasm than that needed to replace protoplasm broken down in the living process. Growth continues longer or more indefinitely in plants than in animals. In a way, plants grow as long as they live. Many instances of this have been observed in various animals. The higher animals, however, have a definite growth period, they attain a mature size and beyond this they do not go. If, in the process of metabolism, they make more protoplasm than they can use, the extra amount is excreted although some may be stored in the form of fat.

Adaptation. Animals quickly adjust themselves to changes in external conditions. Plants also constantly adjust themselves to such changes, but more slowly. Most animals make the proper adjustments by the aid of their sensory, nervous and locomotor systems. The plant makes its adjustment by the process of growth and hence the response is slower. Plants at times are destroyed by agencies from which animals can easily move to a place of safety.

There are various types of changes in external conditions which affect living organisms. For example, there are physical changes when objects come into contact with the organism. These are recognized as mechanical stimuli. Then there are changes in temperature and variations in light. Chemical changes are variations in water and the concentration of salts, alkalis, acids, oxygen and carbon dioxide surrounding the plant. The plant protoplasm, especially that of cells immediately affected by the stimulus is sensitive to changes. This sensitiveness is known as irritability. The change in environmental conditions which produces a response is called a stimulus. It probably brings about a temporary modification in the physico-chemical constitution of the cells "irritated."

In animals, sensory cells are stimulated and the chemico-physical change is converted into a nerve impulse which presently brings about a movement by the locomotor apparatus. The plant makes a response also, but this is accomplished by growth. More cells are formed in one place than in another and the plant slowly turns *in an appropriate response.* Plants have no nerves and no muscles. A turning or a response to a stimulus is called a *tropism.* If the response is toward the stimulus, the tropism is positive; if away, it is negative. The clinging growth of the ivy to the wall is an example of positive thigmotropism. The growth of the root at right angles to the surface of the earth toward the earth's center is an example of positive geotropism in which the stimulus is gravity; the growth of the stem in the opposite direction from the root is an example of negative geotropism; the growth of a stem toward the light is an example of positive phototropism, while the roots exhibit negative phototropism; the extensive growth of the root system toward a greater water supply is an example of positive hydrotropism. The root tip is so sensitive to appropriate stimuli that Darwin was led to say that "there is no structure in plants more wonderful as far as its functions are concerned, than the tip of the radicle —." Gager points out the importance of these tropisms to agriculture. As one illustration of this, he points out that it makes little difference how seeds fall when planted, since positive geotropism will cause the root sooner or later to grow down. It would be practically impossible to plant crops if every single seed had to be placed with the embryonic radicle pointing downward and the epicotyl upward. If the top of a tree is removed, one of the remaining topmost *lateral* branches grows *upward* and in a few years there is little evidence of the earlier injury. This is not only negative response to gravity and positive phototropism, but involves other obscure processes. While the main stem and main root show direct response to such stimuli, the growth response of branches, as a rule, is at an angle to the stimulus and branch roots are transversely geotropic. It must be remembered that the whole organism is subjected simultaneously to a number of stimuli. Because of this, no one stimulus is, as a rule, evidenced to the elimination of the effects of a stimulus of another type. The position of the plant as a whole is the net result of all the stimuli acting upon it. In order to ascertain the effect of one stimulus, the investigator must maintain all but one type of stimulus as usual and change that one stimulus markedly and then note the effect that this has on the growth response. Suppose we arrange sprouting seeds so that all the conditions are normal except that the radicle is at a right angle to the force of gravity. Slowly we can see that the root turns in growth downward. Or, we can admit light to one side of a plant only. Gradually it will grow toward the light. It is an interesting problem to study the position of leaves of different types of plants and trees. We see leaves of different size and arrangements, and see that in general leaves are placed so as to secure optimum illumination for all.

In some plants the response to contact is relatively rapid. This is true of the Mimosa — the sensitive plant. This plant has many, small, pinnately divided leaves. If we strike the tip of one of these, the leaflets close up toward each other, beginning at the tip where the stimulus was applied. If the stimulus is stronger, then the petiole also bends down and if the stimulus is still stronger, other leaves respond until the whole plant responds. The reaction suggests that some type of impulse is being communicated. The response occurs at the rate of from 8 mm. to 20 mm. per second, *i.e.*, too rapid to be a growth phenomenon. It has been shown by Ricca that the stimulated part secretes a chemical substance which passes into the circulating system and as it passes other parts, causes them to react. But this type of response is ordinarily not manifested in plants.

B. General Biology of Roots, Stem and Leaf

Relation of Roots to Water and Soil. The principal functions of roots are to anchor the plant firmly to the ground; to absorb water and mineral matter from the soil; to absorb oxygen, to give out carbon dioxide; to store water and food and to support plants which do not possess rigid stems, but which clamber over other plants. If most of the roots are removed, the plant dies. We can cut off a stem near the ground and new stems grow up again, but serious injury to the root system will usually kill the plant. Corn plants (Fig. 97) develop bracing or prop roots near the base of the stem. Roots grow out into the soil seeking the optimum water and food supply. Liebig once said that they apparently had eyes for this purpose. This is not literally true, of course. It can be explained as a growth response to the stimulus of water. If necessary, roots will grow deep into the soil after water. Plants require a great amount of water in growth and in formation of seeds. Briggs and Schantz found that wheat requires 500 times as much water by weight as the dried weight of the seed produced, corn over 350 times as much and potatoes over 600 times as much. Grovesnor reports that cane plants absorb 1000 pounds of water to make one pound of sugar. Few people realize the extent of the root system. This matter has been extensively investigated by Weaver — in the case of many hundred plants. For example, mature Marquis wheat plants, about 2.5 feet high, have a very thick root system for three feet in depth and some roots extend into the soil for a distance of six feet. Roots hold or bind the top soil together and prevent it from being washed away by the rain. Complete destruction of forests oftentimes has been followed by the loss of the top soil which is rich in plant food. This top soil is essential to plant growth. The destruction of forests also decreases the rainfall. It is claimed that on this account areas of the earth's surface, once fertile, are now barren. The fertility of a region depends partly upon the mineral content of the top soil, on the amount of nitrates, phosphates and humus present. Great quantities of this top soil are washed annually by the rain into rivers and so into the sea.

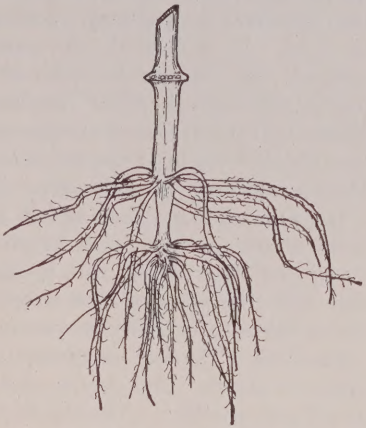

FIG. 97. — Lower end of corn stem showing upper tier of "prop" roots formed after the earth around the stem was "hilled up."

Although most roots cannot breathe if immersed in water, yet some plants are so constituted as to permit this. Roots of willow trees growing alongside a stream are often submerged in the water and the trees seem to thrive. On the other hand, some plants grow in the air and their roots can take in moisture from the air. Some plants can be propagated from roots. For example, the dahlia possesses a *multiple* fleshy root. When one of the roots is placed in the ground in the spring, a new dahlia plant develops. Pieces of the root of rose bushes, when carefully handled, will produce new rose plants. Poplar trees grow very rapidly. When once started, and if the conditions are favorable, these trees form long roots and from these roots many new young poplar trees spring up. Some seed plants live on other seed plants. The first type may be partially or wholly parasitic on the second — the host. In such cases, the parasite sends a special modified root into the tissue of the stem of the host and thus derives its food supply from the host. In this way the dodder which has no chlorophyll or leaves obtains sugar and mineral salts. The mistletoe obtains chiefly mineral salts and water from its host. Mistletoe has pale green leaves.

It has been found that certain molds grow on the tips of the roots of certain trees, such as pines, oaks and beeches. These Fungi cover the root tips with a tangled mass of threads and probably take the place of root hairs. Moreover, the trees do not thrive unless these Fungi are present.

The Soil. The *soil* constitutes one of the two great environments of plants. The greater part of the weight of soil is made up of rock particles. The size of these particles varies and they are of irregular shape, with air spaces here and there between them. Well-tilled soil makes for a greater number of air spaces. Plants will not grow well in very compact soil. Rain falling upon loose soil percolates slowly down through it. If the soil is packed down, the rain does not penetrate but runs off. If the soil is composed exclusively of rock particles, it penetrates too rapidly and may collect over waterproof layers too far beneath plants to be of any use to them. If the rock particles are mixed with decayed organic matter, or humus, the surface water not only percolates more slowly through the soil, but more is retained. In comparatively dry soils a thin film of water is found adhering to the rock particles. This is of little use to the plant because the rootlets do not possess the power to remove this hygroscopic film. However, if the soil is of the proper constitution, a considerable supply of water will be found associated with it in the same way as water associates itself with the cotton fibers of a lamp wick, namely, by capillarity. If the tips of the roots are absorbing this capillary water from one point, the adjacent water of capillarity will move from the points of greater saturation to the region of less saturation. Air is vitally necessary for the life of the ordinary root unless there is some special structure present to obviate the immediate absorption of water directly by the root. Well-tilled soil makes for greater water-holding power, for conservation of water and for ample air supply. It also removes accumulations of carbon dioxide and encourages the destruction of injurious Bacteria by exposure of the soil to sunlight. Otherwise such Bacteria may accumulate in the soil.

Water dissolves chemical substances necessary for plant growth. Compounds of sulphur, potassium, calcium, magnesium, phosphorus, iron and nitrogen are found in soil. These elements occur in soil water as carbonates, sulfates and nitrates. The compounds of calcium tend to neutralize soil acids which are injurious to plant growth. Magnesium is needed in the formation of chlorophyll, and this important compound cannot be produced unless an iron compound is present in the cell sap. Potassium salts appear to aid in the formation of carbohydrates. Some proteins contain phosphorus and sulfur and of course these elements must be present in compounds which are soluble in cell fluids. The roots of some plants, such as the potato, appear to be able to absorb weak ammonia solution although this is injurious to most plants. Long-continued growth of crops on a certain area of land diminishes the amount of soil minerals. Unless they are restored to the soil, the crops grown will be failures. The principle involved in the use of commercial fertilizers is to restore these compounds to the soil.

Organic matter comes from the decay of dead animals and plants. Certain groups of bacteria break down the complex compounds of dead tissue into simpler and simpler compounds. The final results are water, carbon dioxide, ammonia and the most important of all, nitrates. These soil nitrates are absorbed with the other mineral compounds and are used in the manufacturing of protoplasm. In this process water and oxygen and sugar in the plant cells are also necessary.

Rodents, Insects, Earthworms, Bacteria, Roundworms, Algae, Fungi, etc., inhabit the soil. The living animals burrowing through the soil cultivate it to a certain extent. They aerate it. The beneficial effect of earthworms on soil was thoroughly investigated by Charles Darwin. By far the greatest beneficial work on soils is accomplished by certain types of Bacteria. As stated above, they decompose the dead bodies of plants and animals, and this decomposed organic matter forms humus, and when mixed with rock particles, makes good soil. Certain Bacteria, *Nitrosomonas*, change ammonia into nitrates. *Nitrobacter*, another type of Bacteria, changes nitrites into nitrates.

Roots and Nitrogen Fixation. Bacterium leguminosum, another type of Bacteria, lives in little masses (Fig. 21), nodules or tubercles, on the roots of peas, beans, clover and alfalfa. Over four thousand of these have been found on the root system of a single plant. These Bacteria have the wonderful power of absorbing nitrogen gas from the air in the soil and making a nitrogen compound which can be absorbed by the roots of the plant. In other words, large and vigorous plants may thus grow in soil comparatively poor in nitrates. These are called *nitrogen-fixing Bacteria* and soil may be inoculated with them. The farmer grows a heavy crop of alfalfa enriched by the nitrogen-fixing Bacteria on the roots. He plows this crop under. The crop will decay in the ground and then the soil will be richer in nitrates. The farmer can later grow better crops of corn and wheat on what was previously poor soil. Certain results are of interest here. A crop of clover or alfalfa, plowed under, supplies the soil with about one hundred pounds of nitrogen to the acre. It is as valuable as many loads of manure. A good crop of corn or wheat will remove from fifty to seventy-five pounds of nitrogen per acre from soil.

Root Hairs. The tough bark of old roots is impermeable to the plant fluids within and to the soil water without. But soil fluids must find their way into the plant if life is to go on. Water is needed for the manufacture of more sugar. The sugar supply is constantly used up in the life of the plant. Nitrogen and other necessary elements derived from the soil must enter if the protoplasm, broken down by normal life processes, is to be restored or increased. Root hairs are structures which make possible the intake of water from the soil. The wall of the root-hair cell is permeable to water and to the minerals dissolved in the water. It is lined with a thin film of protoplasm, thus forming a sac of living matter inside of which is cell sap and outside of which is soil water. This protoplasmic sac is not freely permeable. It will not permit the cell sap to escape. In this way the sugar is conserved. It is quite permeable, however, to the substances dissolved in the soil water and to some compounds more than to others. Water can pass through it freely in either direction. Because the concentration of the fluids within is greater than that of the soil water, there will be a movement of fluid from without the cell, through the living membrane into the sap cavity. The concentration of the plant fluids of the inner cells adjacent to the outer root-hair cells is greater than in the latter cells, hence there will be a movement of fluids from the root-hair cells into the next inner row of cells. For similar reasons there will be a movement of liquids from the second tier of cells to the third and from the third to the fourth and so on. Solutions of soil salts diffuse through the cellulose and protoplasmic membranes into the interior of a root-hair cell.

Turgor. Everyone is familiar with the fact that on certain very dry days, small non-woody plants wilt, and that if provided with plenty of water, they again stand vigorously erect. Everyone is familiar with the rigidity developed in an inflated balloon due to the outward pressure of the air imprisoned within. When the balloon is deflated, it becomes flaccid or wilts. The sap cavities of plant cells are well filled with water which has been absorbed and the cells are rigid, due to the outward pressure of the contained fluids on all parts of the cytoplasmic and cellulose membrane. The rigidity of each cell may not be very great, but there are millions of cells and the sum total of all their rigidities is sufficient to maintain erectness. This outward-bearing pressure of contained liquids of a plant cell, due to osmotic pressure, is known as *turgor*. If the cell fluids become depleted due to conditions of drought, then turgor is absent and the plants droop. The cells of the young root possess turgor.

Herb, Shrub and Tree. *Herbs* have relatively soft and tender stems (Fig. 98). These stems die down to the ground during the winter or other unfavorable conditions. New stems grow up when the proper conditions again prevail. A *shrub* is a comparatively low-growing bushy mass of woody stems which do not die down in the winter. Such plants usually do not attain any great size in temperate climates. The lilac is an example of a shrub. A *tree* possesses one main stem or trunk which in some species attains great height and diameter. Its woody structure enables it to support a great mass of leaves and branches. The branching habit of trees is quite characteristic of each species, so much so that in many cases the tree may be identified by its form. The branches bring more leaves into sunlight and air.

Annual, Biennial and Perennial. An *annual plant* is one which develops from the seed, produces roots, stem, leaves, flowers and seed all in one season. Annual plants die down at the end of the summer season. They cannot survive long periods of drought, and winter is a dry period so far as the plant is concerned. The species does not disappear because the plant has produced seeds and it is one of the functions of the seed to protect the embryo from destruction during drought or cold. Examples are peas, beans and many common seed plants. A *biennial plant* develops only roots, stem and leaves from a seed during the first season. It, however, forms a fleshy root in which a surplus of starch made by the leaves is stored. In the spring of the second season another plant develops from the fleshy root. This plant also has stem and leaves but fibrous roots; it also has flowers, and seeds are produced. Two growing seasons are required to complete the cycle. We purchase seeds of beets, carrots and turnips from the seedsman — the harvest is a crop of fleshy roots at the end of the season. But the seedsman plants fleshy roots and raises plants that produce seeds.

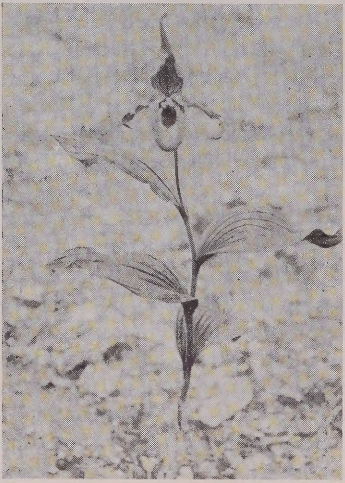

FIG. 98. — Cypripedium, "Lady's Slipper," a perennial herb. The flower is so constructed that insects entering to gather nectar leave pollen from some other Cypripedium and carry off pollen from the flower as they leave. (Photo by Fread.)

Perennial plants such as a shrub and tree live year after year. From the point of view of evolution, perennial plants are regarded as the more ancient type, while herbaceous plants are a recent development. Indeed, it is the opinion of some students that herbaceous or annual plants will become the dominant vegetation of the future. Herbaceous plants grow rapidly, and during the summer time alone, in temperate climates, manufacture enormous quantities of starch and cellulose. Our common crop plants, and especially corn, have been called *sun-energy traps.* Omitting consideration of the grain, farm wastes such as corn-stalks and straw of our country alone contain, it has been said, potential energy equivalent to our entire output of soft coal and gasoline. Annual plants seem to be more vigorous power transformers than perennials.

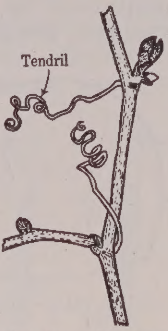

Fig. 99. — Tendrils of wild grape.

Modifications of Stems and Leaves. The cactus is a green stem whose spines are modified branches. The green part of a cactus plant is virtually stem tissue in which food is made and stored. The so-called leaves of "Smilax," a decorative plant, are flattened branches, while the tendrils of the pea are modified leaflets, and those of the grape (Fig. 99) are branches. When a young tendril establishes contact, the outer tissue grows more rapidly than that next the support, with the result that the tendril *grows* tightly around it. This reaction to contact is called *thigmotaxis.* The English Ivy is supported on walls by aerial roots. In the Virginia Creeper, the ends of the tendrils have discs which stick to walls (Fig. 100).

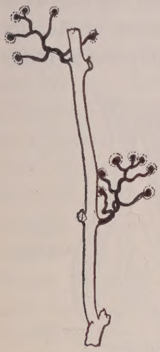

Fig. 100. — Holdfasts at ends of tendrils (branches) of Virginia Creeper.

Rate of Growth. Corn plants may grow ten feet high in one season. Pine trees are only three inches high at the end of the same period. Some species of pines grow fifteen inches a year for the first fifty years; then five inches per year during the next fifty years. They may live two hundred years, but during the second century grow but an inch or so in height each year. Hardwood trees grow but part of an inch in thickness during the first half century and after that but a fraction of an inch per year. Forest fires destroy such growths of wood in a few hours. A pine tree takes fifty or more years to produce wood enough to make a board twelve inches wide, one inch thick and twelve feet long.

Size and Age. Stems vary in size, and in some cases it is difficult to recognize the stem, as in the dandelion plant, where the leaves grow in a rosette almost from one point. Some plants have slender stems, but they thrive by climbing up over other plants or on the side of buildings, as is the case with the Virginia Creeper. The giant redwood, Sequoia, is one of the tallest, largest and oldest of all living organisms. The largest and oldest specimen is "General Sherman" a tree in the Sequoia National Park. It is 280 feet high, 36.5 feet in diameter and probably nearly 4000 years old.

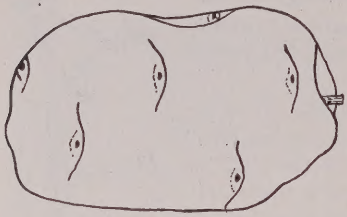

FIG. 101. — Tuber of potato plant.

Storage of Food. We have already noted that the rhizome of the fern is an underground stem. Many seed plants have underground stems also. The *tuber* of the potato (Fig. 101) is the terminal portion of a specialized underground stem in which starch is stored. The " eyes " contain buds and each of these can produce a new plant. The food for the early growth of this new plant is derived from the starch stored in the potato. The fleshy body of beets and carrots is a storage root. The stem is very small but from it arise numerous leaves. The bulb of the onion or Narcissus (Fig. 102) has a small, short, broad stem covered with fleshy storage leaves. In all these cases, food stored in stem, root or leaf is used for growth of the new plant.

Pruning. Trees tend to produce an excessive number of buds, branches and leaves with the result that many die and sooner or later are broken off. This is a sort of natural pruning. Intelligent pruning of trees by man is an important part of forestry practice. However the cut surfaces should be painted over to prevent entrance of fungus spores and thus avoid disease. It has been observed that a fruit tree if neglected will produce a wealth of branches but little fruit. With correct pruning greater growth energy goes into the production of larger and better fruit. In the case of plants grown for flowers, removal of some of the flower

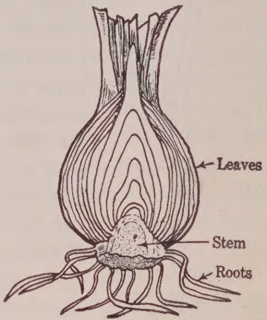

FIG. 102. — Section of Narcissus bulb.

buds will result in fewer but larger and more perfect flowers. Single giant chrysanthemums and dahlias are produced by saving only the most promising-looking bud.

Origin of New Varieties and Grafting. New varieties have been produced by cross-pollinating closely related forms. The resulting type is known as a "hybrid." It often happens that such hybrids do not breed true, *i.e.*, their seed does not produce offspring similar to themselves. Very often the hybrid possesses very superior qualities. Man has discovered, however, that the new type can be preserved and cultivated by a sort of vegetative reproduction. This is accomplished by a process called *grafting*. An example of how this is done is given here (Fig. 103). Very young saplings are grown from the seed of a hardy variety of the same but relatively useless kind so far as fruit is concerned. The stem of this plant is cut off near the ground. The cut is made in a special way. To the cut end of the stem connected with the root system of the hardy plant is attached the cut end of a branch of the hybrid which grows the new variety of fruit. The branch is called a *cion* and the plant to which it is attached is called the *stock*. Cion and stock are fitted with the cambium tissue of each in contact. They are securely fastened together and the *bandage* coated with *grafting wax*. The branch grows to the stock and from both will develop a fruitful tree. This new tree is practically the offspring of the parent hybrid. In this way, the hybrid variety can be perpetuated indefinitely. Seedless grapes and navel oranges are propagated in this way. It is thought that seedless oranges once appeared on a branch of an ordinary orange tree. The sudden appearance of a variation differing distinctly from the usual range of variations is called a *sport*. Grafting is employed in the commercial production of most of our fruit trees and such shrubs as roses.

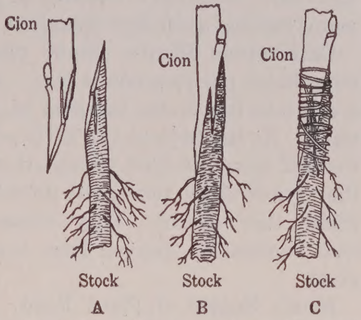

FIG. 103. — Root grafting. *A*. Cion and stock prepared for joining; *B*. Cion and stock joined; *C*. Cion and stock tied securely with waxed cord. From Gager: *General Botany*, copyright 1926, P. Blakiston's Son & Co., reprinted by permission.

New varieties of potatoes are produced by cross-pollination, but the new variety is continued commercially by vegetative propagation, since the farmer plants pieces of potatoes and not seed. On the other hand, the inventor of new varieties of grain, produced by experimental cross-breeding, is forced to plant the new seed produced. The application of principles of heredity discovered in the course of modern research in genetics has brought success in many cases of grain hybridization.

Carnivorous Plants. Some plants are carnivorous, but this remarkable phenomenon is rare. In the pitcher plant, the pitcher is a special leaf on the inside of which are stiff hairs pointing downward. At the bottom is a little pool of water. Special glands on the leaf secrete a fluid which attracts insects. When they enter, they crawl about inside the pitcher and some fall into the water where they drown. They decompose and are digested. The food compounds derived from their bodies are absorbed by the plant.

Man's Supply of Plant Food. Although a great amount of the world's supply of starchy foods is stored in underground stems and roots, yet the main supply is formed in seeds. The thin watery sirup of the sugar-cane stem is one source of commercial sugar. The juice of the sugar beet (storage root) is another important source of sugar.

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PART II

THE BIOLOGY OF ANIMALS

CHAPTER VIII

PROTOZOA

Definition of Animal. The word *animal* is derived from the Latin, *anima,* which literally means 'breath,' and derived from this is the idea, 'spirit,' for the *spirit* or soul is that which leaves the body with the last breath or 'spiritus.' After all, breathing movements are characteristically more distinctive of the living animals which most people observe. The complete absence of breathing movements is one of the commonest indications of death. It is probable that gradually the idea developed that breathing was associated with the ability of a living animal to move about, so that today the word 'animal' connotes *movement* rather than the more literal idea of mere *breathing.*

And yet the popular conception of 'animal' as an organism that moves about does not agree with the scientific idea since many animals, such as the corals, do not move about. On the other hand, many minute plants do move about.

Plants and Animals. It is practically impossible to absolutely differentiate between animals and plants. In addition to movement, there are other characteristics which separate most plants from animals. For example, the plant cell is usually inclosed in a cellulose box, the rigidity of which is not adapted to rapid movement from place to place. Animal cells, on the other hand, are bounded by a soft cell membrane and this property is related to the possibilities of free movements of animals. In the next place, animals possess an adjustment mechanism making possible rapid changes in position in response to sudden modifications of the environment, which affect the animal. Adjustment in plants takes place slowly. Plants do not possess the specialized organs of sensation, conduction and contraction of animals. Animals possess sensory organs and nervous and muscular systems adapted for the making of rapid adjustments. On the other hand, plants can make carbohydrate and protein compounds from inorganic ingredients.

Animals cannot do this. They are dependent upon plants for *organic* compounds from which they make their *animal* protoplasm. Plants are nearer in this sense to the inorganic world. When the botanist undertakes to make a structural analysis of the plant body, he does not find dissection to be a great help. He is forced almost at once to proceed to a microscopical study of plant tissues. The zoologist, however, finds dissection very helpful since it reveals special organs which perform special functions. After the revelations made by dissection, the zoologist then proceeds to the histological method of analysis.

And yet in spite of those distinctions which separate most plants and animals, there are many minute organisms which are considered plants by botanists and animals by zoologists. This suggests that we should not forget the fundamental resemblances between plants and animals, for the resemblances indicate the fundamental unity of organic nature. The study of different types emphasizes diversity, and we too often forget that all these multitudes of forms are merely various kinds of living *energy transformers* in which certain processes are common to all and these very processes distinguish the living from the non-living world.

Protista. One scientific view is, that life first appeared in the form of small microscopic or ultra-microscopic organisms, neither plant nor animal in the modern sense of these words. From these so-called *Protista* (primitive tissue) two great lines of organisms evolved, namely plants and animals. This idea is well depicted by the letter 'Y.' The vertical portion represents the Protista emerging from the inorganic. One arm of the 'Y' represents the evolution of the plants, while the other refers in the same way to the animals. As specialization in body organization succeeds generalization, the later types appear to be more and more diverse.

Animal Phyla. The animal world can be divided into a number of quite distinct groups, each with a similar body plan. These principal subdivisions are called *phyla.* Zoologists differ as to the number of phyla which indicates that classification is a human invention, necessary for any orderly presentation of animal forms.

The following list includes the principal groups or phyla of animals. (1) Protozoa (*e.g.* single-celled forms); (2) Porifera (*e.g.* sponge); (3) Coelenterates (*e.g.* coral); (4) Platyhelminthes (flat worm); (5) Nemathelminthes (round worm); (6) Annelids (earthworm); (7) Rotifera (rotifer); (8) Echinoderms (starfish); (9) Mollusca (clam); (10) Arthropoda (house fly); (11) Chordates (frog).

We shall study some of these groups in more detail than others and note a successive modification of body build from a type which is at first simple to more and more specialized plans. No one individual type is to be considered ancestral to the next higher group. For example, the Amoeba is one of the simplest of Protozoa and yet it would be incorrect to say that Amoeba is the ancestor of the higher groups. We do not know that the early ancestor was like Amoeba in all respects; but the zoologist does believe that the early forms possessed some of the characteristics of present-day simple Protozoa. No one knows what the ancestral forms of each higher phylum were. All that can be done is to conclude from comparative studies, a *few* of the *leading* characteristics of such ancestors.

There are indications of evolution within each group. The comparative morphologist decides which is the more specialized of two forms belonging to the same phylum and in general concludes that such types are less primitive than their simpler relatives.

Protozoa and Metazoa. A fundamental criterion, subdividing the animal kingdom into two groups, has to do with the number of cells constituting the animal body. We can say provisionally that *Protozoa* are single-celled animals. All the functions of life are performed by the single cell. If any physiological division of labor is present, it is accomplished by different structures within the confines of a single cell.

Metazoa are, on the other hand, animals composed of many cells. But this distinction requires further definition. Many Protozoa are organizations of more than one cell; in some cases, the protozoan body consists of hundreds of cells. They are called *Colonial Protozoa.* And yet physiologically each of these many cells functions in the main as though separate from the others; each performs all the metabolic and adjustment functions of life. In the Metazoa, on the other hand, some of the many cells are organized into a special tissue or organ which has a particular function, while other groups of cells form other tissues or organs, *i.e.*, Metazoa exhibit physiological division of labor and tissue differentiation.

PHYLUM — PROTOZOA

Protozoa were discovered by a remarkable Dutch microscopist, Leeuwenhoek, who wrote: "In the year 1675, I discovered living creatures in rainwater which had stood but four days in a new earthen pot, blew within."

Protozoa are small microscopic, single-celled animals or colonies of similar cells. Many types of body form are exhibited. Some Protozoa are in many respects plant-like, while others resemble Bacteria. In the search for the microorganism causing a certain disease, investigators find it impossible to agree since some claim that it is a Protozoan and others that it is a Bacterium. Some Protozoa appear to be simple bits of protoplasm while others are highly differentiated. Protozoa reproduce by fission, by budding, by spores and by eggs and sperm. Protozoa occur in fresh and salt water, in damp earth, in dry dust, inside the bodies of animals and even within cells. So many things have been discovered about them that the distinct science of *Protozoology* has been established. Some protozoologists find that so many general problems of biology are presented by Protozoa, that they consider the group entitled to the rank of a separate sub-kingdom of animals. Each Protozoan appears to be a distinct individual and yet some protozoologists have developed the conception that while Metazoa are animals consisting of differentiated cells, *closely associated in space* to form the body of a single organism, the single-celled Protozoan, on the other hand, is only one cell of a larger organism whose component cells are *separated in space and time.* This conception results from a consideration of the unique life cycles of some Protozoa.

Protozoologists classify them into four groups:

Class I — Sarcodina: *e.g.* Amoeba

These are named from the old word for protoplasm, 'sarcode' or 'flesh.' Among these forms, the genus *Amoeba* is representative, easily obtained and widely studied. It is often referred to by writers discussing the origins of life. However, it is not the simplest of organisms, nor was it the ancestor of higher animals, though it appropriately illustrates our ideas of the nature of these hypothetical ancestors.

Morphology (Fig. 104 *A*). A living Amoeba appears to be a minute, irregular speck of protoplasm in motion. The body is composed of a soft, translucent, watery, jelly-like substance, containing a spherical nucleus, vacuoles, different kinds of granules and lifeless inclusions such as plant and animal fragments and grains of sand. The greater part of the body, containing the granules, for example, is called the endosarc or endoplasm. Surrounding this is a narrow zone of clear protoplasm bounded externally by a film, both constituting the ectosarc or ectoplasm. The Amoeba moves about by thrusting forth blunt lobes or processes of protoplasm called *pseudopodia* (false feet). One can see granules move out into these pseudopodia and back again into the body. The pseudopods are not permanent structures. While new ones form at one place, those at other points disappear as their protoplasm flows back into the main part of the body. One can also observe the formation of a *contractile vacuole.* It increases in size, eventually is located near the ectosarc, bursts and its contents are discharged to the outside.

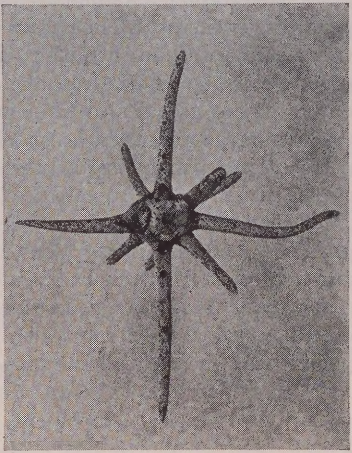

FIG. 104 *A.* — Amoeba proteus. Note the long slender pseudopodia. (Photo of model in American Museum of Natural History.) Courtesy A. M. N. H.

Physiology. Physiological activities can be divided into three groups: Metabolism, Adjustment and Reproduction.

First — Metabolism. (*a*) Ingestion of food. Amoeba feeds on microscopic plants and animals. The protoplasm of the Amoeba appears to flow around the food particle, which, with some of the water, becomes a spherical *food vacuole* in the endoplasm.

(*b*) Secretion. Appropriate enzymes from the surrounding cytoplasm mingle with the fluid of the vacuole.

(*c*) Digestion. The enzymes convert the insoluble food into simpler and more soluble compounds.

(*d*) Absorption. The digested food compounds are absorbed into the surrounding protoplasm.

(*e*) Egestion. The food vacuole has decreased in size. It now contains only undigested residues such as silica, walls of diatoms or cellulose from plant cells. Eventually, these bits come to the surface and are discharged.

(*f*) Circulation. The absorbed food compounds are distributed throughout the body of the animal by the moving protoplasm.

(*g*) Assimilation. The absorbed food compounds together with water and salts are transformed into new protoplasm.

(*h*) Respiration. Assimilation and other activities involve expenditure of energy. The release of energy in protoplasmic activities requires the presence of oxygen. Respiration refers to that process whereby oxygen from the air is brought to the seat of oxidative processes and also the elimination of CO_2. Oxygen is in solution in the water which Amoeba takes in with its food. Oxygen is also probably absorbed through the surface of the body and circulated as food is circulated.

(*i*) Oxidation. Oxidation occurs whenever and wherever energy phenomena are manifested, such as the movements of adjustment and processes of metabolism and reproduction. Energy is thus made available for living processes. Physiological oxidations at moderate or low temperatures are like oxidations of organic compounds when heated to high temperatures.

(*j*) Excretion. As a result of oxidations, protoplasm disintegrates into simpler compounds. Not only protein but carbohydrate and fat may be thus oxidized. The by-products are of no further use to the organism, and indeed of positive detriment if retained, and are therefore discharged, *i.e.*, *excreted.* Chief among these by-products are nitrogenous compounds such as urea, $(NH_2)_2CO$, water and carbon dioxide. Some investigators appear to have demonstrated that the contractile vacuole collects these products of *katabolism*, which term applies to all the destructive stages of metabolism. *Anabolism*, its companion term, refers to constructive phases of metabolism. Some Protozoa do not possess contractile vacuoles and yet must excrete. Cells of metazoan animals have no contractile vacuoles and discharge wastes directly through the cell membrane. However, this argument does not disprove the excretory function of the contractile vacuole of Amoeba, while the demonstration, by microchemical methods of nitrogenous wastes within the vacuole, largely confirms its function as an organ of excretion. It is also a regulator of water content.

All the *processes* noted above occur in the metabolism of Metazoans.

Second — Adjustment. Observers of the movements of Amoeba marvel at this phenomenon. Those who have studied it conclude that Amoeba is not aimlessly moving about but that it exhibits a definite orderly adjustment to varying external conditions. It has no sense organs, yet is sensitive to appropriate stimuli, as, for example, sudden contact with some object; it possesses no nerves, yet the change aroused by the stimulus is effectively communicated throughout the body; it possesses no muscles, yet can move from place to place in an adequate manner. Let us examine the mechanism of movement alone. This has intrigued the interest of many investigators and yet no single explanation is satisfactory to all observers. One idea is that it rolls along in much the same manner as a "caterpillar" tractor. But such a machine puts forth no pseudopodia and appears simple, compared with the Amoeba. Another idea is that the Amoeba walks on its pseudopodia.[1] Amoeba is positively attracted to the substratum on which it 'crawls'; it is positively attracted to food particles but sometimes takes in grains of sand. It moves away from apparently injurious chemical stimuli. Some have concluded from such observations that the behavior of Amoeba is a series of tropisms, *i.e.*, direct mechanical responses to stimuli. But its behavior at times is more complex than this. For example it exhibits a certain degree of selection when ingesting. Jennings was so impressed by the performance of this animal that he went so far as to say that "if Amoeba were so large as to come within our everyday ken, I believe, beyond question, that we should find similar attribution to it of certain states of consciousness."

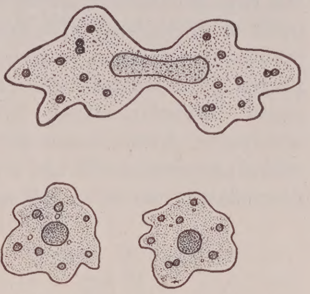

Fig. 104 *B*. — Reproduction in Amoeba.

Third — Reproduction. A single Amoeba has been observed to divide (Fig. 104 *B*), forming two small Amoebas which grow to adult size and divide again. After a number of divisions of this sort, individuals undergo encystment and sporulation, a process which is imperfectly understood. Apparently small spore-like forms emerge which develop into the larger form. Then follows a period of reproduction by fission. In other words, a cycle is present with life phases comparable to those of a higher organism.

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[1] Amoeboid-like change of form induced by changes in surface tension may be observed in certain chemical mixtures, *e.g.* — cover a drop of mercury in a watch glass with a 2% solution of nitric acid. Place a small crystal of potassium dichromate near the mercury.

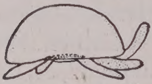

FIG. 105.—Arcella.

Sarcodina in General. Sarcodina include various forms. *Arcella* (Fig. 105) has a dome-shaped brown shell which it secretes, and its pseudopodia extend out through a circular opening on the flat surface of the shell. *Difflugia* (Fig. 106) has a more elongated, somewhat ovoid-shaped shell made of particles of sand. Both forms can withdraw into the shell. *Actinophrys* (Fig. 107) is a tiny, vacuolated, spherical mass of protoplasm with long pointed pseudopodia, each supported by a central axial filament. *Radiolaria* (Fig. 108) are marine forms, some with radiating pseudopodia and a porous, chitinous shell dividing inner protoplasm from outer. Some have a lattice-like skeleton of silica of varying patterns. The *Foraminifera* (Fig. 109) have a network of pseudopods around the entire animal or part of it. Many have a calcareous shell. The skeletons or shells of these dead Protozoa sink to the bottom of the sea, forming great deposits many of which have later been lifted up to form sedimentary rock, which may be found far above and far away from the ocean. The chalk cliffs of England, many feet in thickness, are the compressed skeletons of innumerable Foraminifera, once

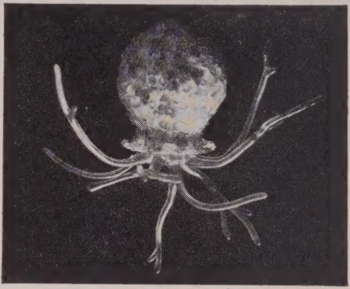

FIG. 106. — Photo of model of Difflugia. (Courtesy of American Museum of Natural History.)

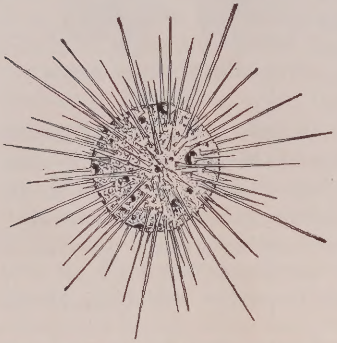

FIG. 107.—Actinophrys. From Conn: *Fresh Water Protozoa of Connecticut*, Connecticut Geological and Natural History Survey.

living animals of the sea. Nummulistic limestone, of which the great blocks forming the Pyramids are composed, is foraminiferal in origin.

Amoebic or tropical dysentery is caused by a Sarcodina-like parasite introduced by way of the mouth with water, milk or other articles of food. The specific organism is called *Entameba histolytica. Entameba coli* is a frequent inhabitant of the human digestive tract. Other types appear in the feces of many animals, including man.

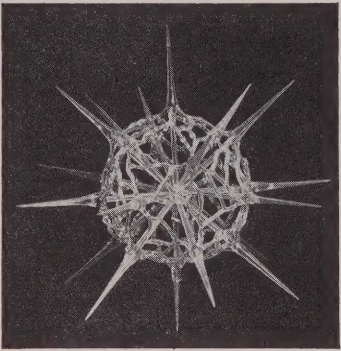

Fig. 108. — Photo of model of skeleton of a Radiolarian. (Courtesy American Museum of Natural History.)

Class II — Mastigophora or Flagellates

These are forms in which the motor mechanism consists of one or more elongated whip-like processes called flagella. They may be divided into two groups: (*a*) animal-like and (*b*) plant-like types. In many respects they are more primitive than the Sarcodina because the same individual may exhibit metabolic peculiarities of both plants and animals.

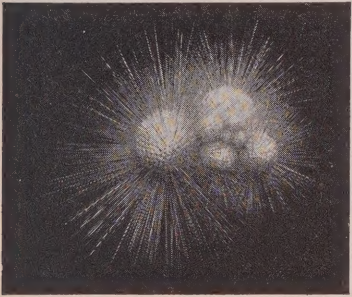

Fig. 109.—Globigerina bulloides, a Foraminifer. (From photo, Courtesy American Museum of Natural History.)

Euglena. Euglena is an example of this class. The form of the body is definite (Fig. 110). It is somewhat elongated, pointed at one end and rounded at the other. From the latter projects the long vibratile *flagellum* which arises from a slit called the mouth. The flagellum acts as a propeller in front of the animal, and drags the animal behind it. The mouth leads into a short 'gullet.' Contractile vacuoles discharge into a reservoir which in turn discharges into the 'gullet.' Nearby is a small mass of red pigment called the eye or *stigma* because it is thought to be especially sensitive to light. There is one nucleus, and there are many green chlorophyll-containing bodies in the cytoplasm. Utilizing the energy of the sun, the chlorophyll can manufacture a carbohydrate substance, *paramylum*, from carbon dioxide and water. Euglena may also ingest microorganisms like Bacteria, and digest them in food vacuoles. Some types may live at times on decaying organic matter. Some Euglenas have two phases in their life cycle. In the active phase they reproduce by fission lengthwise. In the passive phase they encyst, and subdivide into many small cells, which afterwards are released, form flagella, and resume the active phase again. In many Mastigophora, conjugation, similar to that occurring in the Alga, Ulothrix, has been observed.

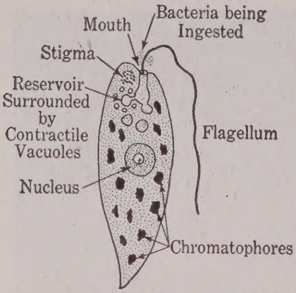

Fig. 110. — Euglena. Modified from Curtis and Guthrie (after Tannreuther): *Text Book of General Zoology*, copyright 1927, John Wiley & Sons, Inc. Reprinted by permission.

Synura (Fig. 111) is a colonial, plant-like flagellate which is often responsible for offensive odors and tastes in water supplies. The organism forms fats or oils and it is these which impart the disagreeable qualities to the water. Some flagellates contain chromatophores of one color or another. For example, areas on the surface of the ocean may be orange in color, due to the flagellate form *Noctiluca*, or colored red with vast numbers of *Peridinium*. Phosphorescence in the sea is due in part to the rapid oxidation of small particles of oil produced by Noctiluca. African sleeping sickness is caused by

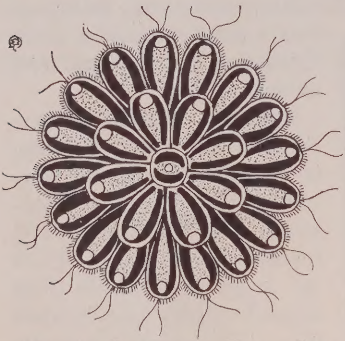

Fig. 111. — Synura. From Conn: *Fresh Water Protozoa of Connecticut.* Courtesy Conn. Geological and Natural History Survey.

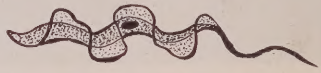

Fig. 112. — Trypanasome. From Hegner (after Calkins College Zoology. Macmillan Co. Reprinted by permission.)

Trypanosoma gambiense (Fig. 112). This flagellate is parasitic in the digestive tract of the Tsetse fly (Fig. 113), a blood-sucking insect. If an infected fly bites a person, it may introduce these parasites into the blood stream of the human victim, where it multiplies. Other Trypanosomes are harmless parasites in the blood of the frog and rat.

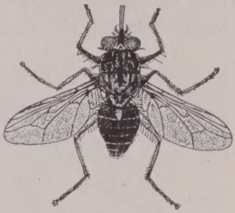

Fig. 113. — Tsetse Fly. (From drawing by Howard, U. S. D. A.)

Certain colonial flagellates are of theoretical interest. Two are here described.

Pandorina (Fig. 114). It consists of a spherical colony of sixteen cells, each provided with two flagella and surrounded or inclosed in a thin case. When the colony is mature, each cell divides four times to form sixteen cells each, *i.e.*, a small colony. These sixteen colonies break through the case, and each develops into a new colony.

Volvox (Fig. 115). This is a spherical, colonial form. The outer wall of the sphere is one layer of similar cells, thousands in number, each provided with two flagella. The interior of the sphere is filled with fluid. Each of the cells performs all the functions of metabolism and adjustment. There is no differentiation into organs. However, reproduction is effected by special cells and is asexual or sexual. In *asexual reproduction,* certain cells derived from the body wall cells, *i.e.*, somatic cells, multiply into small spherical colonies within the sphere. Later they are freed from the mother colony and become mature colonies. In *sexual reproduction,* certain cells just inside the colony wall become greatly enlarged, due to storage of nutriment in them, and form eggs. Other cells, derived also from the body wall cells and also located just within the body wall, divide and subdivide, forming small bi-flagellated, free-swimming sperm cells. Some species of this genus are *monoecious* and some *dioecious*. *Sexual reproduction is established therefore in the so-called lowest phylum of animals.* Many other Protozoa have a sexual as well as

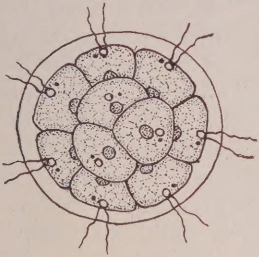

Fig. 114. — Pandorina. From Curtis and Guthrie (after Oltmann): *Text Book of General Zoology,* copyright 1927, John Wiley & Sons, reprinted by permission.

an asexual phase in their life cycle. Pandorina and Volvox are mentioned here because the development of many higher animals, belonging to different groups, exhibits embryonic stages which resemble those of Pandorina and Volvox. Furthermore, continuing this thought, biologists are wont to regard the fertilized egg of higher forms as homologous with single-celled Protozoa. Botanists include Pandorina and Volvox with the Algae. Although Volvox consists of many cells, yet there is present an integration of activities. The organism is the biological unit.

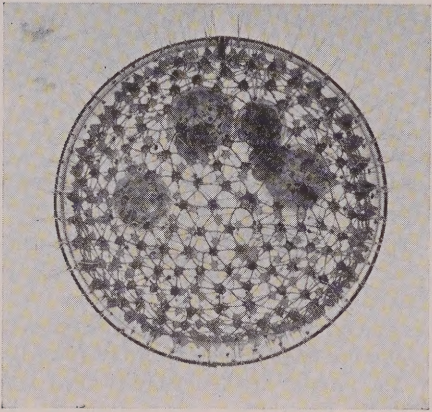

Fig. 115. — Volvox. Photo of model. (Courtesy American Museum of Natural History.)

Class III — Infusoria or Ciliates

In this class the organs of locomotion are cilia which many Infusoria possess during all phases of the life cycle while some types have cilia only in the early stage of development. One of the commonest forms is the genus Paramoecium, found in decaying *infusions* of such material as hay or other organic matter. It is easily kept in laboratory cultures.

Morphology. Paramoecium (Fig. 116) is called the 'slipper animalcule' because its outline is similar to that of a slipper with pointed toe and rounded heel. The blunt end is regarded as anterior. On one side, at this end, is the *oral groove* which extends obliquely back to about the middle of the animal. At the posterior end of this groove is the mouth, opening into a short, blind *gullet*. In the gullet is an *undulating membrane* formed by a fusion of cilia into a band which in motion directs water, containing food, into the body. Granular endoplasm and hyaline ectoplasm are present. A thin, firm cuticle forms the outer limiting membrane, preserving the definite body shape. The surface is covered with regularly arranged cilia. Just within the cuticle is a narrow, striated zone containing defense bodies called *trichocysts*.

Near the middle is a large *vegetative meganucleus* and a small *reproductive micronucleus* near it. Two *contractile vacuoles* are present, one near each end of the animal. Many *food vacuoles* are present. Behind the oral groove at the posterior end is the *anal spot,* from which undigested food matters are discharged. It is evident that Paramoecium is more highly organized than Amoeba. It illustrates the high degree of specialization characteristic of many single-celled forms.

Physiology. *Locomotion.* In moving about, Paramoecium takes a spiral course, at the same time turning on its longitudinal axis. The forward and rotating movements are brought about by whip-like lashing of the cilia backward and to the left. The spiral course is also explained by the fact that the cilia of the oral groove beat stronger than other cilia, and so tend to swing the front end of the body out of the straightforward direction. Paramoecium glides quickly into the field of microvision and out again, making careful observation difficult until it is quiet.

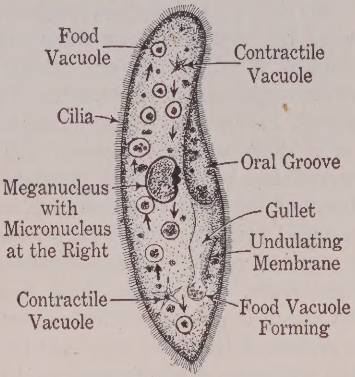

FIG. 116. — Paramoecium. Modified from Conn: *Fresh Water Protozoa of Connecticut.* Courtesy Conn. Geological and Natural History Survey.

Feeding. The peculiar method of progression enables it to explore a wider field when in search of food. When it finds a spot rich in Bacteria, for example, it becomes quiet. The cilia of the oral groove sweep quantities of food-laden water into the mouth, forming a pocket at the blind end of the gullet. Presently this 'food pocket' breaks into the protoplasm and is called a *food vacuole,* which moves toward the rear in the endoplasm. Others form and follow, one after the other. From the rear, they move toward the anterior end, then turn again toward the rear. During this *circulation* of food vacuoles, digestion takes place; digested products are diffused and the undigested residues are voided at the anal spot.

Action of Vacuoles. The radiating canals of the vacuoles extend out into the neighboring cytoplasm. Much water is taken in with the food. This collects in the radiating or drainage canals which discharge it into the central reservoirs and these when full empty their contents out through the cuticle. The vacuoles function alternately and with a certain rhythm. They probably maintain a water equilibrium and at the same time remove excretions. Other processes of metabolism are similar to those of Amoeba.

Behavior. A few years ago some biologists were inclined to view the movements of forms like Paramoecium as manifestations of a simple mechanism and from experiments with it and other organisms developed the Theory of Tropisms. In moving about, Paramoecium may approach an unfavorable medium such as a drop of salt solution. It exhibits indications of being stimulated by it. Then it backs away, turns to one side, the front of the body describing an arc, and glides forward again on a spiral course. If it again comes within the unfavorable zone, it again reverses, turns in a different direction and moves forward once more. It repeats these movements until it finds a course on which it proceeds. This is called the *avoiding reaction.* It is a system of trial and error and by this method the organism finds the optimum environment as to food, temperature, light and other stimili. Although Paramoecium has no sense organs, yet it is sensitive; we know that impulses are transmitted within the body and Rees by special methods claims he has found special fibers which transmit such impulses. Such fibrils have been found in other forms. These fibers may be homologous with delicate fibrils in the nerve fibers of Metazoa.

Trichocysts are sticky, thread-like bodies, which are discharged in reactions of defense, when, for example, a Paramoecium is attacked by some other Protozoan.

Reproduction. Paramoecium reproduces by binary *fission.* The animal divides transversely, forming two daughter cells. Each becomes complete in all its parts and each grows to adult size, and divides again. From *one* to *four* divisions *may* take place in twenty-four hours. If the rate is four divisions per day, by the end of the first day a single Paramoecium of this kind would be represented by sixteen descendants; if all lived, at the end of two days by 256 animals and at the end of three days by 4096 and so on. Many die, however; otherwise the world would soon be occupied by a mass of Paramoecia. At times, two individuals *conjugate* (Fig. 117), *i.e.*, come together and remain in contact for some time. During this period, the meganuclei disintegrate, while the micronuclei undergo a series of divisions and some of the resulting micronuclei disintegrate also. But finally a micronuclear body from each animal *passes over* into the *other cell* and fuses with a micronuclear body *still remaining* in the other conjugant. The animals separate. A new nuclear outfit is reorganized in each. Other nuclear changes occur before they again reproduce by binary fission. This phenomenon is restricted to the Infusoria but is not characteristic of all of them. Maupas claimed that conjugation must occur every so often, as a rejuvenating process. Woodruff, however, has kept P. aurelia without conjugation (*i.e.*, reproducing regularly by fission) since 1907. In this period he has handled thousands of generations. He has, however, supplied them with suitable food and other environmental conditions which would not be present in a state of nature. Under more natural conditions they do conjugate after many fission generations. When they are about to conjugate, a single individual, if isolated and prevented from conjugating, undergoes a complicated process of nuclear reorganization, somewhat like that in conjugation, after which it divides by fission. This process is called *endomixis*. Conjugations in certain Sarcodina and Mastigophora are of the usual type, that is, one cell formed by the fusion of two. This is a real union of gametes to form a zygote. In Paramoecium, the conjugants separate. In P. calkinsi, Spencer found that neither conjugation nor endomixis seemed necessary. Conjugation seems to have a rejuvenating effect under some conditions among certain types. It is similar to fertilization in that it affords an opportunity for the combination of two protoplasmic strains, thus giving a *chance* for

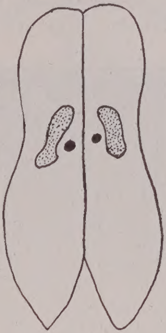
FIG. 117. — Conjugation in Paramoecium.

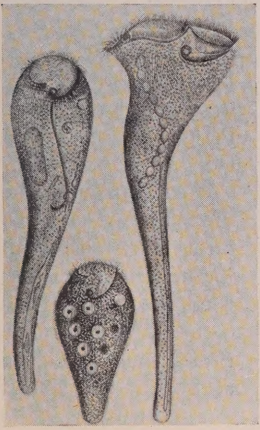
FIG. 118. — Stentor polymorphus, Müller. Courtesy American Museum of Natural History.

new types of individuals more fitted for an environmental condition unsuited to the continued existence of the forms before conjugation.

Infusoria in General. There are many forms of Infusoria. *Stentor* (Fig. 118) is trumpet-shaped when attached and at rest. The nucleus is sometimes long and bead-like. *Vorticella* (Fig. 119) has a bell-like body attached to a long stalk, the lower end of which is attached. The stalk contains a contractile thread which quickly coils up when the bell is stimulated. The animal retracts and extends in various directions searching for food organisms. *Stylonichia* (Fig. 120) has not only fine cilia, but a few larger and stiffer processes by means of which it moves or creeps along.

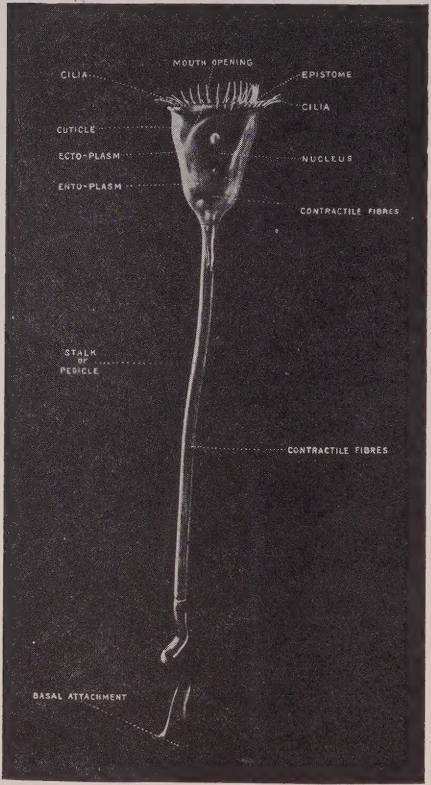
CILIA
MOUTH OPENING
EPISTOME
CILIA
CUTICLE
ECTO-PLASM
NUCLEUS
ENTO-PLASM
CONTRACTILE FIBRES
STALK OR PEDICLE
CONTRACTILE FIBRES
BASAL ATTACHMENT

FIG. 119. — Vorticella. Photo of model. Courtesy American Museum of Natural History.

A comparison of the morphology of two forms like Amoeba and Paramoecium indicates that evolution has occurred within the Protozoan group. The highly differentiated Paramoecium exhibits within the confines of its single cell structures which may be considered organs. It is reasonable to conclude that forms like Paramoecium have traveled a long way from the primitive Protozoa — the first emergent forms of animal life.

Although consisting of but a single cell, yet observation of the behavior of Protozoa impresses one with the fact that they are independent living beings possessing individuality. One looks down through the microscope to a world on the other side of the "looking glass" — a world occupied by wonderful creatures busily occupied with activities which we interpret as being very important to them.

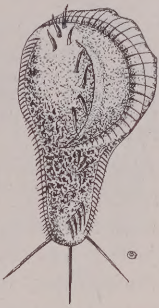

FIG. 120. — Stylonichia. From Conn: *Fresh Water Protozoa of Connecticut.* Courtesy Conn. Geological and Natural History Survey.

Class IV — Sporozoa

The Sporozoa (Fig. 121) are parasitic and many have no organs of locomotion. As the name indicates, the formation of spores is a distinct phase in their life history. One species, Porospora gigantea, often found in the gut of the lobster, may grow to be 16 mm. long. Some Sporozoa are parasitic within the body cavity of animals, some in the intestinal tract, some within the cytoplasm of a tissue cell and some are even intranuclear. They have a destructive effect upon cells. Manson, in 1907, stated that "The pathogenic Protozoa are responsible probably for a very large number of diseases." Sporozoa are transmitted to man chiefly by contact with objects containing them; as, for example, eating food contaminated with their spores. Again, an animal may be infected by some other intermediate host. Malaria is caused by a Sporozoan. For a long time it was thought that it was caused by breathing in the damp air from swampy regions. Varro about twenty centuries ago suggested the relation between malaria and the mosquito. A long series of investigations during the last quarter of the nineteenth century by many workers has corroborated this ancient supposition. The causative agent is a Sporozoan belonging to the genus Plasmodium. Different malarias are caused by different specific organisms. The intermediate host is the mosquito belonging to the genus Anopheles. Of about fifty known species of Anopheles, about sixteen are malarial carriers.

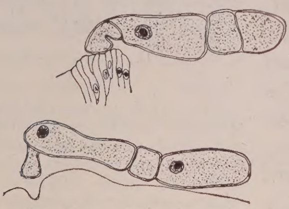

FIG. 121.—Gregarina—from intestine of meal worm, *i.e.*, the larva of Tenebrio beetle.

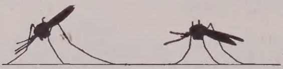

FIG. 122. — Anopheles mosquito on the left; Culex on the right. Courtesy American Museum of Natural History.

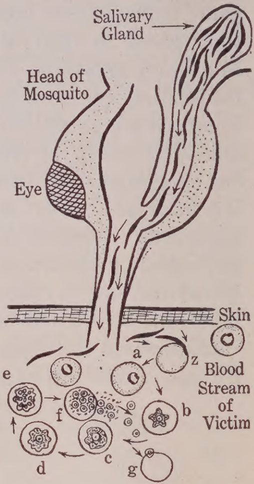

FIG. 123. — Anopheles mosquito injecting sporozoites of malarial organism into blood stream and development of the sporozoite within corpuscles. At z, a sporozoite is entering a corpuscle; stages a, b, c, d, e, f follow. Many spores escaping at f; one entering another corpuscle at g.

However, the presence of such mosquitoes in a region does not necessarily make the district malarial. In addition to the mosquitoes there must be persons who are carriers of the Plasmodium or who are suffering from the disease. The parasite is transmitted by female Anopheles (Fig. 122), since they are blood-sucking while the males feed on plant material. In withdrawing blood from the victim, the mosquito injects saliva containing a substance which prevents coagulation of the blood. If the mosquito is carrying Plasmodium sporozoites (motile spores) (Fig. 123), these are injected into the human blood stream during this process. The introduced parasites at once invade the red blood cells. There they reproduce by sporulation, and in due time a great many small spores escape from the corpuscle, which is thus destroyed. At the same time waste products including toxins are introduced into the blood stream. The liberated spores at once enter other corpuscles, later sporulate there and still later discharge many more Plasmodia spores and toxins into the blood. This process may increase to such an extent that the patient has chills and fever, becoming more severe as each new and larger crop of spores is discharged. The rapidly increasing destruction of the red blood cells is also a serious menace. After a period of reproduction by sporulation, the Plasmodia develop into male and female gametocytes. If a female Anopheles sucks blood (Fig. 124) at such a stage, these cells become gametes in the stomach of the mosquito. The gametes unite, forming zygotes which migrate through the wall of the stomach and encyst on its outer surface. Many cysts form on the wall of the stomach. Later, sporozoites emerge from the cysts and make their way into the salivary glands, from whence they may be discharged into a human victim when attacked by such a mosquito. Quinine sulfate given to malarial sufferers kills the parasites in most cases. However the surer method of ridding a country of malaria is to rid it of mosquitoes. That this can be done successfully was shown when the yellow-fever and malarial-infested Panama Canal Zone was turned into a model health resort. Waite writes: "Of all the insect-borne diseases malaria is the most important. It has been estimated that directly or indirectly it is responsible for more than half of the deaths of the human race. There are probably more than a million cases of malarial fever every year in the Southern States alone." And yet prophylactic measures resulting in the reduction or elimination of the mosquito and the isolation of the malarial patient has brought about the practical disappearance of this disease from many districts. Many persons of the younger generation in certain parts of the country know little about it and many of the

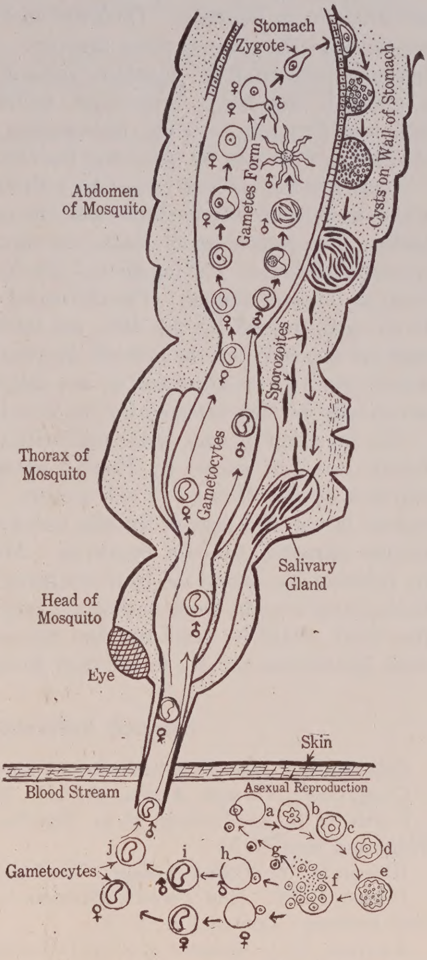
Stomach
Zygote
Cysts on Wall of Stomach
Gametes Form
Abdomen of Mosquito
Sporozoites
Thorax of Mosquito
Gametocytes
Salivary Gland
Head of Mosquito
Eye
Skin
Blood Stream
Asexual Reproduction
a
b
c
d
e
f
g
h
i
j
Gametocytes
♀
♂

FIG. 124. — Life cycle of malarial parasite in blood stream and in body of Anopheles mosquito. Adapted from Schaudinn *et al.*

younger physicians have little professional experience with it. This is an index of the value of scientific research, for by it thousands of lives have been saved and many thousands of dollars.

It is very difficult to determine whether *certain* parasitic forms are Protozoa or Bacteria. Doubtful microorganisms of this nature appear to be the cause of many diseases. For example, some investigators claim that the organism causing Syphilis is a Protozoan, a parasitic flagellate, Treponema pallidum. Others classify it with the Protophyta. The Spirochaeta of Relapsing Fever are claimed as Protozoa by some and Bacteria by others.

Texas fever of cattle is caused by a Protozoan, Babesia bigemina, which lives in an intermediate host, the cattle tick (Fig. 219), Boophilus. The percentage of deaths among cattle is high. The disease spreads as follows: The female tick fills her body with blood sucked from an infested animal. The distended tick drops to the ground. Even eggs, formed by this tick, are infected. Fertilized infected eggs are deposited on the ground, develop into young infected ticks which crawl up on grass and so are able to find a passing animal, which may be thus infected for the first time.

The infection of eggs while still within the infected body of a female was first shown by Pasteur about 1865 in his classic researches on the diseases of silk worms. Pasteur discovered that moths, larvae and eggs of the silk worm were infected with a protozoan parasite, Nosema bombysis. Moreover, the larva could be infected by eating infected mulberry leaves. Only by establishing new broods, from uninfected moths feeding on protozoan-free food, could he eradicate the disease which had threatened with destruction the silk industry of France.

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CHAPTER IX

PORIFERA AND COELENTERATA

Porifera, *e.g.*, sponges, and Coelenterata, *e.g.*, jelly fishes, are called *Diploblastic Animals.* By this is meant that the body consists of two differentiated cell layers called *ectoderm* and *endoderm.* All the Metazoa are *diploblastic* during their early development.

Formation of Ectoderm and Endoderm. The fertilized egg divides into 2, 4, 8, 16, etc., cells (Fig. 303), often forming a spherical clump of cells resembling Pandorina, a stage known as the *Morula* (Fig. 303). The cells continue to divide and a cavity forms within the cell mass, which, remaining spherical, consists of but one layer of cells, about a central *segmentation cavity.* It resembles the Protozoan, Volvox. This stage is known as the *Blastula* (Fig. 305). Then in many Metazoa, cells at one point in the blastula divide more rapidly than the others and *invaginate* into the *segmentation cavity.* The ingrowing cells form a blind tube or sac within the outer cell layer. Thus a double sac is formed. This stage is known as the *Gastrula* (Fig. 305). The inner blind tube is the embryonic intestine, composed of *endoderm* cells. The function of this embryonic intestine, or *archenteron* as it is called, is in general *metabolic, i.e.,* it develops structures having to do with ingestion, secretion, digestion, etc. The outer layer of cells constitutes the *ectoderm,* which is concerned with the functions of *adjustment.* The entrance to the archenteron is the *blastopore,* and it serves as a mouth and an anus. The gastrulae of some Metazoa function as free-living organisms soon after gastrulation is completed. Such a gastrula has to provide its own food from without in order to complete its development. In other cases, this stage is passed through quickly, and energy for development is derived from material stored up within or adjacent to the cells, or from the mother.

PHYLUM — PORIFERA

The Porifera or sponges are *diploblastic Metazoa,* but their early development is unlike that of the other Metazoa. The early embryo swims about but later settles down with the blastopore at the bottom. This closes and the body, being urn- or flask-shaped (Fig. 125), develops a *new* opening at the free or opposite end. The body wall develops complicated passageways (Fig. 126) or pores through which water enters the central cavity. Microorganisms are taken up by appropriate cells lining the passages and so the animal feeds. Water currents pass out through the opening or *osculum* at the free end. Sponges were formerly considered plants on account of their lack of motion and because of their vegetative habits. They differ in so many ways from the remaining Metazoa that they have been called Parazoa, or *alongside animals.* There are about 2500 species. A few may be regarded as simple individuals, while many, such as the common bath sponge, *Euspongia* (Fig. 127), are associations of units with a complicated common system of waterways. The bath sponge of commerce is merely the skeleton of what was once a living animal. Its skeleton is composed of spongin, a nitrogeneous compound similar in some ways to silk. In other sponges, the skeleton consists in part or wholly of silica as shown by *Euplectella* (Fig. 128), Venus Flower Basket, and *Hyalonema* (Fig. 129), the Glass-Rope Sponge. It is said that flint

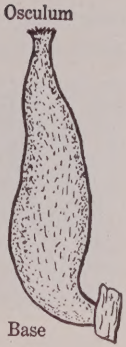
Osculum
Base

FIG. 125. — Grantia, a simple sponge.

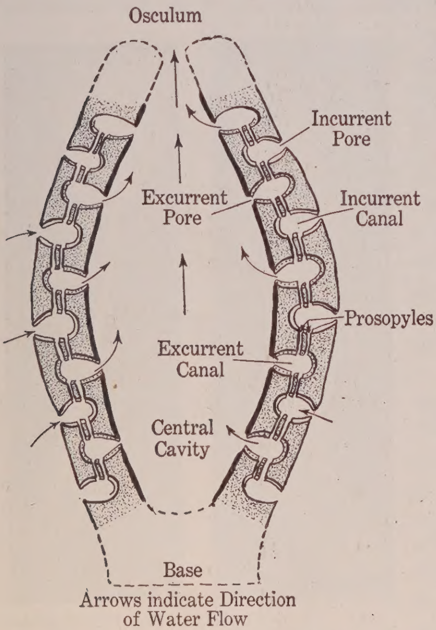
Osculum
Incurrent Pore
Excurrent Pore
Incurrent Canal
Prosopyles
Excurrent Canal
Central Cavity
Base
Arrows indicate Direction of Water Flow

FIG. 126. — Plan of anatomy of a simple sponge.

rocks have been produced in part at least by marine sponges which abstracted silicon from seawater in forming skeletons. Porifera are regarded as an offshoot from the early Metazoa and not in the main line of evolution.

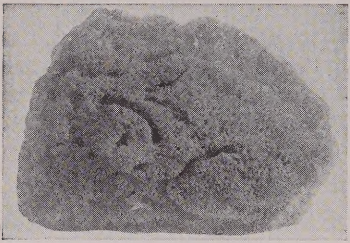
FIG. 127. — Euspongia. (Skeleton.)

PHYLUM — COELENTERATA

All the remaining Metazoa form a *diploblastic* embryo which is *gastrula-like* with *ectoderm* and *endoderm*, the latter forming an *archenteron*. The Coelenterates are the simplest of these. Although they have only two germ layers — ectoderm and endoderm — yet each of these is differentiated into a number of types of special cells. Some Coelenterates are free-swimming forms and some are sedentary, and some have a life history with an *alternation* of *generations* in which the *sedentary* stage is *asexual* while the *free-swimming* stage is *sexual*. The body exhibits *radial symmetry* — that is, one finds similar structures in any two vertical planes radiating from the central vertical axis.

Type 1. Hydra. Morphology. Hydra (Fig. 130) is a common fresh-water genus. It is tubular in form, about 5 mm. in length and attached at the basal (foot or *aboral*) end. At the free or *oral* end is the mouth in the center of a small conical enlargement,

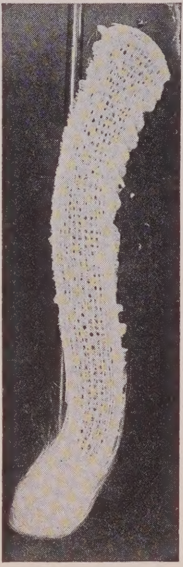
FIG. 128. — Skeleton of Euplectella, Venus Flower Basket.

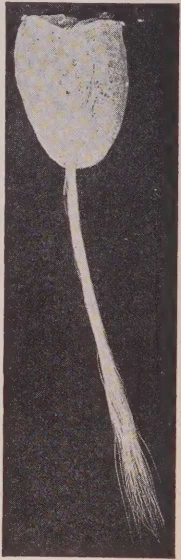
FIG. 129. — Skeleton of Hyalonema, Glass-Rope Sponge.

the *hypostome,* at the basal margin of which are the *tentacles,* below which is the cylindrical body. The mouth opens into the simple *enteric* or gut cavity. The body wall consists of two layers of cells, and hence Hydra, like all Coelenterates, is a *diploblastic* animal. The *endoderm* cells are somewhat larger than those of the *ectoderm.* Between the two layers is a thin and quite non-cellular substance called *mesogloea,* into which cells from the endoderm may migrate. In *Hydra viridis,* the endoderm cells contain small Chlorophyceae, which live there symbiotically. The structure of the tentacles is similar to that of the body, and each has a cavity continuous with that of the body. On the body wall near the tentacles, *testes* may be found and lower down, *ovaries.* Finally a slight swelling on the body may be the *bud* of a new Hydra; or a *young Hydra* which has developed from a bud may occur there. In spite of its apparent simplicity, Hydra exhibits a considerable degree of cell differentiation.

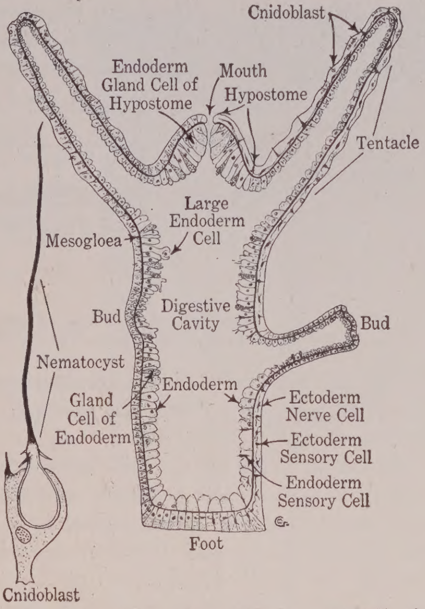
Cnidoblast
Endoderm
Gland Cell of
Hypostome
Mouth
Hypostome
Tentacle
Large
Endoderm
Cell
Mesogloea
Digestive
Cavity
Bud
Bud
Nematocyst
Endoderm
Gland
Cell of
Endoderm
Ectoderm
Nerve Cell
Ectoderm
Sensory Cell
Endoderm
Sensory Cell
G.
Foot
Cnidoblast

FIG. 130. — Morphology of Hydra. From Curtis and Guthrie: *Text Book of General Zoology* — copyright 1927, John Wiley & Sons, Inc. Reprinted by permission.

Structure of the Ectoderm (Fig. 131). Most of the ectodermal cells of Hydra are columnar in form, but the bases of many project into lateral processes attached to the mesogloea. The deeper processes are contractile so that the whole cell is *epithelio-muscular.* Epithelium is a tissue composed often of cubical or columnar-shaped cells forming a membrane. Between the *epithelio-muscular* cells are (1) *sensory cells,* spindle-shaped, with pointed tips and at the base provided with branching extensions running lengthwise of the body; (2) *nerve cells,* near the mesogloea, and having branching processes which with others form a *nerve net* over the entire body; (3) *neuro-sensory* cells, or nerve cells that have sensory fibers running to the surface, and finally, (4) *cnidoblasts* (Figs. 130 and 131). These last are special cells found chiefly in the tentacles. They have a cavity inclosing a *nematocyst,* a flask-shaped body with a long, pointed, thread-like process coiled up inside. Extending from the free surface of the cnidoblast is a small, trigger-like process, the *cnidocil.* The testes and ovaries develop from ectoderm cells.

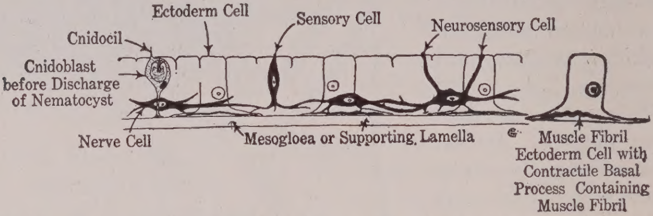
Ectoderm Cell
Sensory Cell
Neurosensory Cell
Cnidocil
Cnidoblast before Discharge of Nematocyst
Nerve Cell
Mesogloea or Supporting Lamella
Muscle Fibril
Ectoderm Cell with Contractile Basal Process Containing Muscle Fibril

FIG. 131. — Hydra. Structure of ectoderm. From Curtis and Guthrie: *Text Book of General Zoology,* copyright 1927, John Wiley & Sons. Reprinted by permission.

Endoderm (Fig. 130). This layer consists of larger columnar cells with the muscular processes at their basal ends. These processes on the inside of the mesogloea are at *right angles* to the long axis of the body and therefore function as circular muscles. Around the mouth opening and at the basal end of the tentacles these muscular processes are well developed. Centrally the endoderm cells have processes which extend into the digestive canal. Some especially large endodermal cells are thought to be unicellular glands. There are also a few nerve cells and sensory cells in this layer.

Physiology. *Metabolism.* With body and tentacles extended, the green hydra waits for small organisms to come in contact with its tentacles. If the "feeding" is poor, it contracts and extends its body in another direction. It may even change its location. If a small organism hits the projecting trigger or cnidocil of a cnidoblast cell, a nematocyst is discharged. This penetrates the prey and also paralyzes it. Many nematocysts may be discharged. Then the tentacles bring the food to the mouth. "Hungry" Hydras voraciously ingest food. Small food particles may be taken into endoderm cells and digested in intracellular food vacuoles as in Amoeba. However, most food is digested in the upper part of the gastric cavity. Endoderm cells secrete enzymes which are discharged to mix with the food in this cavity. Undigested fragments are egested through the mouth, sometimes *shot out.* With the mouth closed and body contracting, the digested food products come into contact with the endodermal lining of the enteric cavity and those of the tentacles. The food is absorbed, circulated slowly to all other cells and assimilated. Excretion occurs at the free surfaces of all exposed cells, probably chiefly from the external surface.

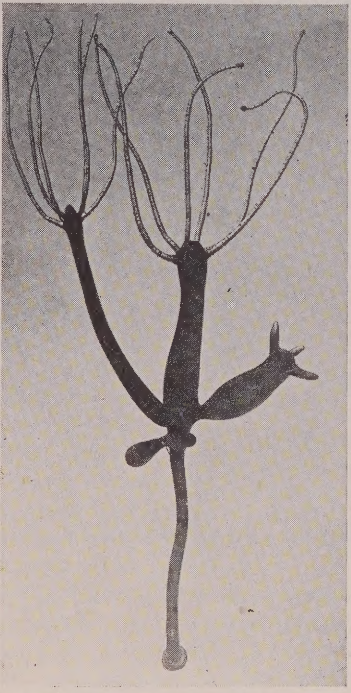

FIG. 132. — Hydra fusca with four buds in various stages of growth. (Photo of model in Am. Mus. Nat. History.)

Movement. The body and tentacles contract, becoming shorter and thicker or expand, becoming longer and thinner. The animal can bend its body and change its position from place to place. It can loosen its hold on the substratum and glide or hitch or somersault. Its behavior is a series of reflexes which are reactions carried on by reflex mechanisms. The latter have three parts: (*a*) a Receptor, *i.e.,* sensory part *excited* by the stimulus; (*b*) Adjustor, for *conducting* the impulse and (*c*) Effector or muscular part, the activity (or contraction) of which *produces the movement.* A review of the histology of the ectoderm indicates that Hydra is provided with such mechanisms. By these, adjustments are made to new conditions with which the animal is constantly confronted. For example, a single epithelio-muscular cell is a complete, though primitive, reflex machine in which the exposed portion of the cell is receptor, the middle part, adjustor, and the contractile part, effector. Then again a stimulus may irritate certain sensory ectodermal cells. The physico-chemical change brought about in these cells is communicated to the ectodermal *nerve net,* which distributes the impulse to all contractile elements. Hydra is positively thigmotropic, soon attaching itself after being forcibly torn from its resting place. It is very sensitive to mechanical stimulation, for it contracts if the aquarium is even *slightly* jarred. It locates in positions *optimum* as to light, temperature, chemical and other environmental conditions. Small organisms on which Hydras feed may collect in well-lighted areas so that Hydras will gather in those same areas.

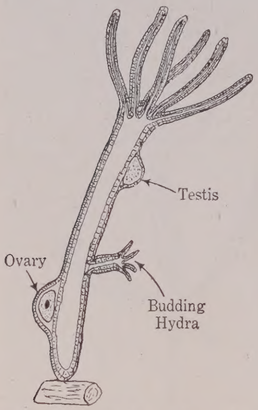

FIG. 133. — Hydra. Reproductive organs.

Reproduction. (*a*) *Budding.* This is asexual. A blind outgrowth (Fig. 130) of the body wall involving both endoderm and ectoderm takes place. Tentacles appear, a mouth is formed and after attaining a certain size the basal end of the young Hydra closes the connection with the parent body (Fig. 132) and later becomes detached.

(*b*) *Sexual Reproduction.* Both sex organs may form at the same time, or testis first and ovary later. They are formed from ectoderm (Fig. 133). The testis is a sac containing flagellated cells, the *spermatozoa,* which are discharged from the testis capsule into the water outside. From another ectodermal cell an ovary is developed. This consists of a thin capsule containing one *ovum.* When mature, the capsule of the testis splits open, permitting sperm to swim about so that they fertilize the eggs of other Hydras. Gamete formation occurs in the autumn, the embryo passes the winter within a cyst, and development is completed in the spring.

Embryology. The fertilized cell divides and continues to divide, forming a *Morula* and later a hollow sphere of cells called the *Blastula.* Later ectoderm and endoderm cells are differentiated from the blastula and tentacles are formed. The embryo drops from the cyst, becomes attached at its basal end, the digestive cavity forms within the endoderm, and a mouth appears. Its *gastrula* character is evident.

Regeneration. If Amoebas are cut into pieces containing nuclear material, they will grow into mature Amoebas. Porifera possess this power. Hydra also exhibits remarkable powers of *regeneration*. This was first discovered by the Abbé Trembley in 1744. Pieces as small as $\frac{1}{6}$ mm. in length will grow into complete Hydras. Regeneration reminds one of vegetative reproduction in plants. Healing of wounds in the human body involves regeneration of injured cells and tissues.

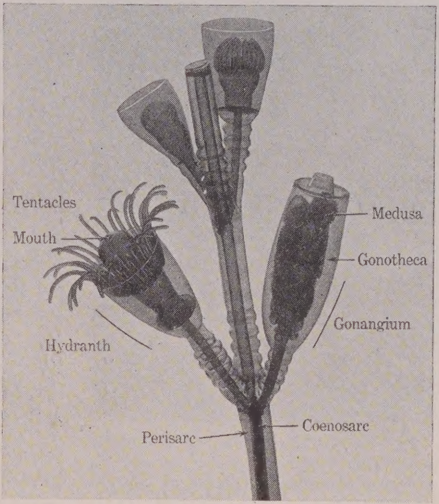

FIG. 134. — Part of an Obelia colony. Photo of model in the American Museum of Natural History.

Type 2. An Obelia Colony (Fig. 134) is a *colonial Coelenterate* which lives in sea-water, where it is attached to submerged objects. A central stem-like part is present from which branches extend. Most of these branches end in hydra-like structures called *Hydranths*, the feeding members of the colony. All other branches end in reproductive individuals called *gonangia*. The soft parts of the colony are protected by a chitinous sheath called the *perisarc*. The soft part of the stem and branches forms the *coenosarc*. The gastric cavity of each Hydranth communicates with a duct in each branch and this with a similar duct in the main stem so that all the vegetative members of the colony are connected by a common gastro-vascular cavity. The coenosarc consists of two layers of cells: outer, ectoderm, and inner, endoderm. The mouth is in the center of a mound-like hypostome. Around the base of the hypostome are about thirty tentacles. The tentacles possess a great many nematocysts. The Obelia colony does not reproduce sexually. The gonangia arise as buds from certain branches. Each gonangium has a central axis, called the *blastostyle*, which produces

Medusae by *budding*. A sac-like covering over the whole structure is the *gonotheca*. The Medusae, when mature, become detached from the blastostyle and escape into the water, through the ruptured end of the gonangium. The jelly-like Medusae (Fig. 135) are very minute umbrella-shaped animals and are free-swimming. They bear sex organs. Some individuals produce sperm and others produce eggs. The fertilized egg undergoes cleavage into two, four, eight, sixteen-cell stages, etc., and a *blastula* and *gastrula* are formed. By further development, the *latter* becomes a new *colony*. Since the *colony* is composed of hydra-like members, all parts of one connected system, it is called a *hydroid colony*. Alternation of generations is present. The *hydroid colony* is the asexual generation and the Medusae constitute the *sexual generation*. Alternation of generations, which is so characteristic of plants, is exhibited by many Coelenterates and is present among other animal phyla.

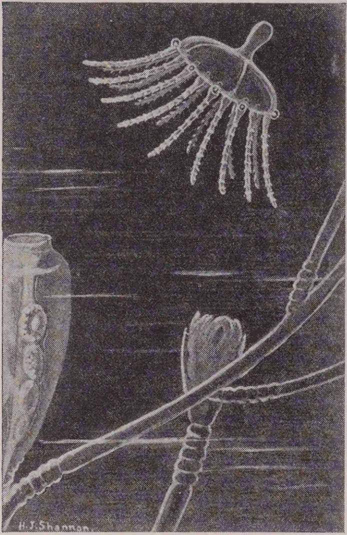

FIG. 135. — Free-swimming Medusa at upper right; gonangium at lower left. (Courtesy American Museum of Natural History.)

Type 3. Gonionemus. The medusa stage of Obelia can be more easily understood by studying *Gonionemus* (Fig. 136), which is a larger form. This *jelly fish*, about a half inch in diameter, looks like a plano-convex mass of jelly. The convex surface is the *exumbrellar surface*, while underneath is the *subumbrellar surface*. Beneath the subumbrellar surface

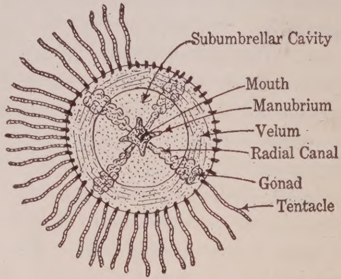

FIG. 136. — Gonionemus, viewed from subumbrellar surface.

is the subumbrellar cavity, bounded below by the *velum*, a flat, narrow, circular shelf with a large central opening (Fig. 137). When the body is relaxed, water fills the subumbrellar cavity through the opening in the velum. When the body contracts, it forces this water out through the velum opening, thus propelling the animal. Gonionemus swims by a series of such acts. Around the margin of the bell are a number of tentacles, and near the base of the tentacles are *statocysts*, organs of equilibrium. Hanging down in the subumbrellar cavity is a stalk-like process — the *manubrium*, with the *mouth* at its outer end. The mouth is the entrance to a canal which leads into the gastric cavity in the jelly-like substance between the exumbrellar and subumbrellar surface. Four radial canals extend at right angles from the gastric cavity out to the margin of the *Medusa*. The gastric cavity and the four radial canals are lined with endoderm. All superficial surfaces are covered with ectoderm. The mass of the animal is the jelly-like mesogloea. A fine circumferential canal runs around the peripheral margin of the animal and the radial canals connect with this. The general structural plan is similar to that of Hydra. The reproductive organs (*gonads*) are located on the under side of the radial canals. The sexes are separate (*dioecious*). Eggs and sperm are discharged into the water, where fertilization takes place. The hydroid stage is very much reduced, but it gives rise to other Gonionemus Medusae by asexual budding.

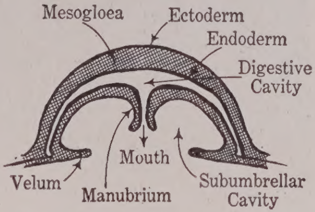

FIG. 137. — Sectional view of a Medusa.

In reviewing these types it is to be noted that in Hydra there is no medusa stage, the animal being able to reproduce by buds or by the sexual method directly; in Gonionemus, there is only a small hydroid stage, while some Medusae have no hydroid stage. In the Coelenterates, therefore, we find different variations of alternation of generations so characteristic of an Obelia colony; but a comparison of Hydra, a Medusa and a Hydranth reveals underlying similarity in body structure although Hydra or the hydroid colony are adapted to a sessile existence and the Medusa to a freely moving life.

Classification

There are over 4000 species of Coelenterates, but all have a body plan essentially like that of a gastrula. The principal classes are:

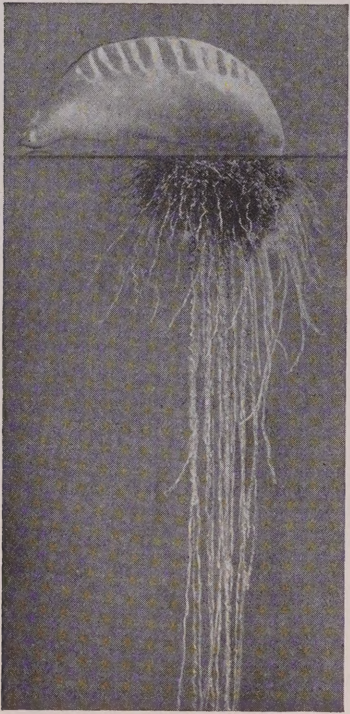

FIG. 138. — Physalia. Photo of model. Courtesy American Museum of Natural History.

Class I. Hydrozoa, to which Hydra, Obelia and Gonionemus and similar forms belong.

Physalia (Fig. 138), the Portuguese Man-of-War, is a compound Hydrozoan. It has the appearance of a beautiful iridescent bladder or float, about six inches long. The prevailing color is blue, although other prismatic colors appear. Underneath the float are feeding, tactile, egg-producing and sperm-producing *individuals.* Still others have long tentacles which, when relaxed, trail down several feet in the water. When a small fish comes in contact with these, the batteries of nematocysts paralyze it, and tentacles, coiling about the fish, raise it up to the feeding polyps. Physalia is of great interest because of the organization into a colony of so many *types* of *individuals.* There is some degree of unity of organization, but not such unity as is shown by the higher animals which are organizations of different systems.

Class II. The Scyphozoa are large forms in which the medusa stage is prominent, while the hydroid or polyp stage is very much reduced. An example is *Aurelia* (Fig. 139), which is common along the North Atlantic coast. It is saucer-like in form and about 2 to 4 inches in diameter and free-swimming. *Cyanea arctica* grows to a great size. Individuals one foot in diameter are common and specimens seven feet in diameter have been seen in northern waters. Some of the jellyfish produce nematocysts with so powerful a poison as to cause serious illness to the unfortunate swimmer who accidentally comes in contact with them.

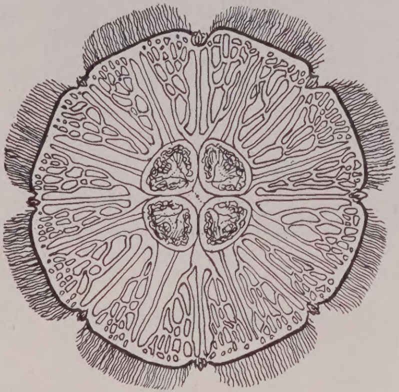
FIG. 139. — Aurelia. Courtesy U. S. Bureau of Fisheries.

Class III. The Actinozoa consist of the sea-anemones and true corals. The prominent stage may be regarded as a *specialized* hydra-like form. *Metridium* (Fig. 140), a sea-anemone, is found along our coast. It is a tubular, sedentary animal about 2 inches long, and attached to rocks or wharf pilings. The free end is crowned by many tentacles. In the center of the free end is the slit-like mouth. *Astrangea* (Fig. 141) is a coral found along the North Atlantic coast. It is a *colony* of individuals each of which resembles, in general, a sea-anemone. At the base of each individual is a substratum of calcium carbonate, coral, which is secreted by the animal. The colony spreads by budding. It reproduces sexually also.

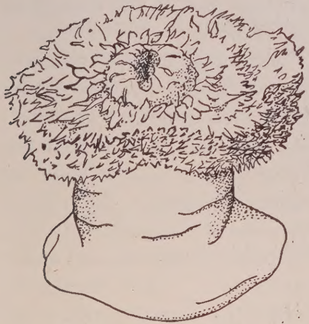
FIG. 140. — Metridium.

Coral polyps build coral reefs and atolls. Colonies of corals are extended by budding. A great variety of form of the compound corals (Figs. 142 and 143) is effected by different methods of budding. There are two kinds of coral reefs. The shore or fringe reef is formed on the sea bottom near the land. There is no direct channel from the outer edge of the reef to the shore, although there are many pools and small channels in which a great variety of marine animals live. A barrier reef is separated from the shore by a wide channel. The Great Barrier Reef (Fig. 144) of Australia is over a thousand miles long with a channel between thirty and sixty miles wide, and from 50 to 175 feet deep.

An *atoll* is an island in the form of a ring with a lagoon inside. The waters of the lagoon are thus protected. The atoll is formed, according to Darwin, by coral colonies at the apex of some subsiding volcanic cone. Growth continues until a comparatively narrow ring of reef extends above the low-water mark.

Coral reefs have existed for untold ages. In the ancient Cambrian Period, the rocks show clear-cut evidence of their presence at that time. Corals have played an important part in the formation of limestone.

Summary: Coelenterata are Metazoa in which the body plan appears to be similar to that of the gastrula stage in the embryology of higher Metazoa. Their body consists of two layers of cells, an outer ectoderm and inner endoderm. The endoderm forms the digestive canal and the opening to it serves both as a mouth and an anus. The body is *radially* symmetrical, and between the ectoderm and endoderm is the jelly-like mesogloea which may contain cells that have migrated into it. Stinging cells

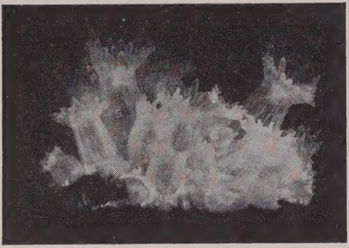

FIG. 141. — Astrangea, star coral. Courtesy American Museum of Natural History.

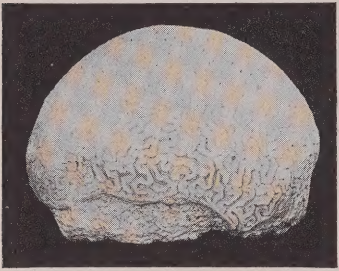

FIG. 142. — Brain coral, Diplora.

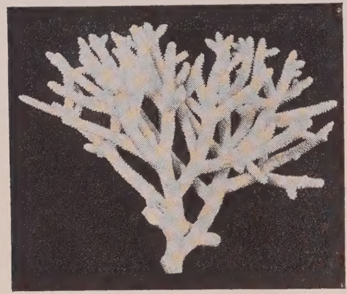

FIG. 143. — Stag Horn Coral, Madrepora.

are characteristic of the group. Metagenesis or Alternation of Generations is present in many types. The more ancient type is thought to be the hydroid or polyp stage, while the free-swimming Medusa is a more specialized development. Both Polyps and Medusae reveal their similarity to Gastrulae. The appearance of ectodermal and endodermal structures has meant the appearance of physiological division of labor, *i.e.*, functions of adjustment being carried out by ectoderm cells and those of metabolism, such as digestion, by endoderm cells. Special reproductive organs, male *and* female, are present.

FIG. 144. — Great Barrier Reef, Australia. Courtesy American Museum of Natural History.

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CHAPTER X

PLATYHELMINTHES; NEMATHELMINTHES; TROCHELMINTHES; ECHINODERMATA

PHYLUM — PLATYHELMINTHES

Triploblastic Metazoa. A characteristic feature of the Metazoa, as the gastrula stage develops further, is the appearance of a *third* embryonic layer between the ectoderm and endoderm. This new tissue or *germ layer* is called *mesoderm.* Platyhelminthes or *flatworms* are called *triploblastic* animals because they exhibit these three germ layers. All the remaining phyla of animals are triploblastic.

Germ Layers. Each of the three *germ layers* forms particular tissues as development proceeds. Ectoderm forms the skin or outer surface tissues and the nervous system; mesoderm forms connective tissues, muscles, reproductive, excretory organs and blood systems, while endoderm forms the lining of the digestive tract and its glands.

Body Form. Other important relations are established by the developing gastrula. The body acquires a definite head and tail end; a definite upper and lower surface and bilateral symmetry. An imaginary vertical plane passing through the longitudinal axis from the mid-dorsal to the mid-ventral line from head to tail divides the animal into a right half which is a duplicate of the left half, or in other words, one half is the " mirror image " of the other half. The relation of these characteristics to forward-moving locomotion is obvious.

Although we noted a certain degree of cell and tissue differentiation in Coelenterates, we find a greater specialization in the flat-worms. This becomes evident in the study of a typical example.

Classification. There are three classes of Platyhelminthes, namely: I. Turbellaria; II. Trematoda; III. Cestoda.

Class I. Turbellaria

Morphology and Physiology. These are free-living forms. Planaria (Fig. 145) is a little fresh-water *flat-worm,* about a centimeter long with a blunt anterior and pointed posterior end. The surface layer of ectoderm cells forming the *epidermis* is ciliated. The mouth opens into the pharynx, located on the ventral side just back of the middle region. The pharynx can be protruded like a proboscis. It leads into the intestine proper, which has three main branches each provided with lateral sacs or tubes. Some portion of the intestine is near almost every part of the body. Food is digested in all of its branches and is absorbed through the endoderm cells which line them. It is transferred to the mesodermal organs near by and to the adjacent ectodermal structures. There is no special circulatory or respiratory system. Oxygen is absorbed by the epidermis and probably by the cells lining the intestine and CO_2 is discharged from them. In the mesoderm is a well-defined excretory system developed from mesoderm. It consists of two long urinary ducts which open to the outside on the dorsal surface toward the rear of the animal. To each of these ducts, a series of side branches is connected. All these tubes are composed of layers of flat cells, while each branch ends peripherally in a *flame cell* (Fig. 146), which has irregular branches extending farther out into the mesoderm. The flame cell possesses a hollow cavity which connects with the end of a urinary tube. At the blind outer end of the cell cavity is a mass of cilia or flagella and, in the body of the cell, vacuoles appear. These resemble the

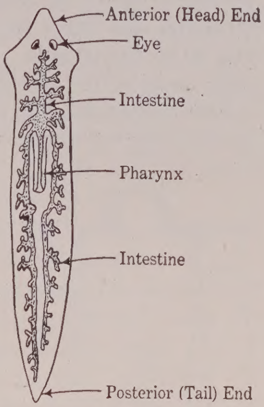

FIG. 145. — Planaria maculata. (After W. C. Curtis.)

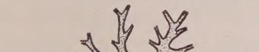

FIG. 146. — Flame cell. From Thomson, *Outlines of Zoology,* D. Appleton & Co., reprinted by permission.

contractile vacuoles of the Protozoa. Evidently wastes are absorbed from the fluids in the mesodermal spaces. These wastes collect in vacuoles in the body of the flame cells and are then discharged into the hollow cavity of these cells. The flame-cell apparatus is one of the simplest of metazoan excretory organs. The vibrating cilia drive the waste fluids into the excretory channels and so to the outside. Probably the contractions of the worm's body assist in the expulsion.

Just underneath the ectoderm is a layer of circularly arranged muscle cells, and under this layer, occur layers of longitudinal and oblique, or vertical muscles which extend from the upper to the lower body wall. There is also *loose* mesodermal tissue present between the intestine and body wall, thus forming tissue spaces filled with body fluid. Contraction of the muscle tissues, aided by ectodermal cilia, accomplish the movements of the worm. Each worm possesses male and female organs (Fig. 147) developed from mesoderm. The *ovaries* are located in the mesoderm in the front portion of the body. Two long *oviducts* extend from the ovaries to the *genital cloaca* or chamber. *Yolk glands* connected with the oviducts secrete yolk about the eggs as the latter pass from the ovaries to the genital chamber. There are a number of *testes* from which the sperm pass into ducts which connect with a pair of long sperm ducts or *vasa deferentia,* which also open by means of a proboscis-like organ, the *penis,* into the genital chamber. Copulation takes place. Sperm from one worm are introduced into the genital chamber of a second worm, whose eggs are thereby fertilized.

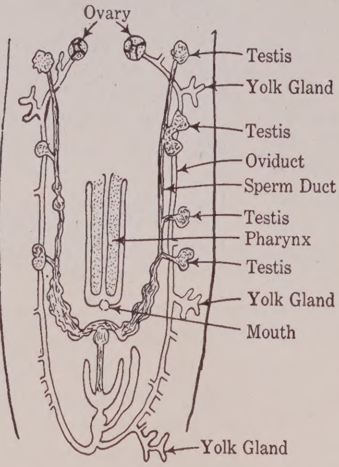

Fig. 147. — Male and female reproductive organs of Planaria simplissima. After W. C. Curtis.

There are two long nerve cords in the lateral regions of the body. Transverse branches from these two strands form a network of nerves. A special concentration of these nerves occurs at the head end. This is regarded as the beginning of the evolution of a brain. Two masses of pigment toward the dorsal surface at the head end and connected by nerves with the "brain" are especially sensitive to light and form rudimentary "eyes." The surface of the body consists of a thin layer of ciliated cells derived from ectoderm. Some of these cells secrete mucus and so are single-celled glands.

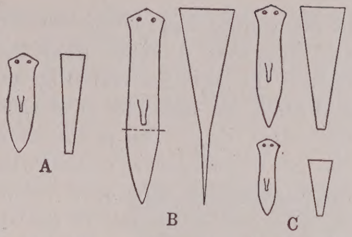

Fig. 148. — Regeneration in Planaria. In A; B and C, the figures at the right indicate variation in metabolic rates. Modified from Newman — *Outlines of General Zoology*, copyright 1924, The Macmillan Co., reprinted by permission.

Regeneration. Planarians possess great powers of *regeneration.* If cut into pieces longitudinally, each part regenerates into a complete whole; if cut in two transversely, both pieces regenerate new worms, the front piece regenerating a new tail, and the hind piece, a new head. Small pieces will regenerate into complete but small worms. The smaller worms have fewer cells than those of normal size. If they are further subdivided, the pieces regenerate into still smaller worms with still fewer cells. A lower limit is determined by the reduction of cells to the point where they are not numerous enough to produce a complete animal.

Asexual Reproduction and Axial Gradients. Large and old Planarians divide spontaneously into two pieces transversely, somewhat posterior to the pharynx. C. M. Child has proposed the theory of *axial gradients* to explain this. By careful chemical tests

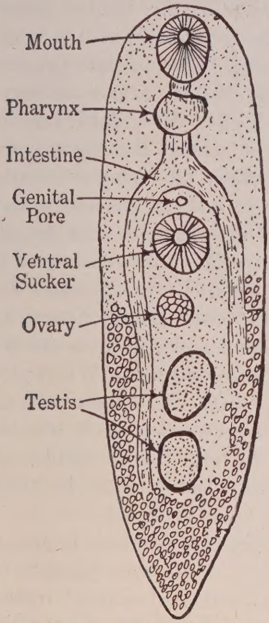

Fig. 149. — Distomum globiporus, a Trematode found in the intestine of the winter flounder. After Linton, Bull. U. S. B. F. 1899.

he determined that metabolic activities are greatest at the head end and that they decrease along the longitudinal axis of the body toward the posterior end (Fig. 148). When the animal is young and small, the high rate of metabolic activity can easily dominate the entire body. But as the animal increases in length and bulk, the rate of metabolism of the entire organism decreases. Furthermore, a point is developed toward the posterior end, where the physiological dominance of the apical end disappears and at this point transverse fission occurs. After the division, a higher rate of metabolism is at once established in the smaller anterior piece and moreover a new center of metabolic dominance is established at the apical end of the hinder piece. Each piece develops into a complete worm. Fission thus appears to bring about rejuvenescence. The work of C. M. Child is important for it attacks *directly* a problem in which all men are vitally interested; namely, the nature and causes of growing old. As stated, Child maintains that senescence is brought about by the gradual decrease in basal metabolism. As long as chemical reactions are reversible, life continues. When protoplasm 'sets,' *i.e.*, when reactions become irreversible, death has arrived. After maturity, the tendency toward this condition of irreversibility increases. The reasons why the decrease in basal metabolism increases with old age must be ascertained.

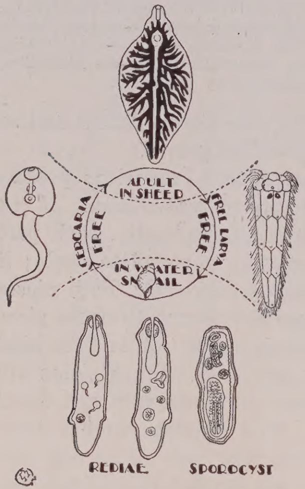

FIG. 150. — Life cycle of liver fluke. From Thomson, *Outlines of Zoology*, D. Appleton & Co., reprinted by permission.

Class II. Trematoda (Fig. 149). They are *parasitic* in many animals. *Fasciola hepatica*, the liver fluke, occurs as a parasite in the liver of the sheep or other domestic animals and causes "rotten liver" and the death of the host. About 3,000,000 sheep were killed in 1879–80 in an epidemic of *sheep rot* in Great Britain. *It has a complicated life history* (Fig. 150). The animal is flat, leaf-like in form, an inch in length by a half inch in width. A single liver may harbor 200 parasites. Each fluke may produce thousands of eggs, which after passing into the sheep's intestine are discharged with feces. The eggs develop into free-swimming embryos and fresh-water snails act as necessary intermediate hosts before infestation of other sheep can occur. Eight species of liver flukes may infest man. The Chinese liver fluke, *Chlonorchis sinensis*, is common in man, dogs, cats and pigs, in China and Japan. The liver may become enlarged, jaundice result and also gastro-intestinal disturbances. The parasite is transmitted through eating raw or imperfectly cooked fish in which the immature stages occur. Other species which infest the intestinal tract are common in man, in India and China. One species lives in the lungs of man and is the cause of pulmonary hemorrhages. It is common in Japan and neighboring islands. Transmission is brought about by eating imperfectly cooked crabs and crayfish, in which one of the stages in the life history of the parasite is passed. Infestation by drinking water containing cysts discharged from crayfish is also possible.

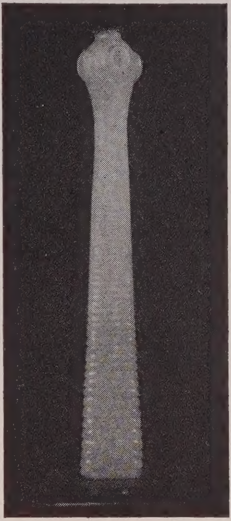

Fig. 151. — Head end of tapeworm, Taenia solium. Photo of model. Courtesy of American Museum of Natural History.

Class III. Cestoda (Fig. 151). **Tapeworms.** There are many species of Cestoda or tapeworms inhabiting the intestine of many kinds of animals. *Taenia solium* is a type which sometimes inhabits the human intestine. The body of the worm is tape-like in appearance, consisting of many segments or *proglottids*. It is bilaterally symmetrical and has a permanent 'head' end or *scolex* with hooks and suckers. New flat proglottids are constantly being formed behind the head, and old 'ripe' proglottids are constantly being dislodged from the hinder end. There is no special vascular, respiratory or digestive system present. Oxygen and digested food are absorbed through the proglottid walls from the contents of the host's intestine. There are well-defined nervous and excretory systems. Each proglottid (Fig. 152) has ovaries and testes and each can produce a great many fertilized eggs. After fertilization *inside the proglottid,* the latter becomes swollen with developing embryos. These proglottids are detached and pass out of the intestine with the feces, thus liberating the embryos. In this stage they may possibly be eaten by a *pig.* In this intermediate host, the embryos (Fig. 153), which possess hooks at the anterior end, bore their way through the intestine into the blood vessels and are carried by the blood stream to various organs. Usually most of them are found in the connective tissue of the muscles and encyst there. The hooks disappear, the embryo increases in size and from one side there develops a bud which grows into the cavity of the bladder-like form of the embryo. On account of this form, these asexual passive stages are called *bladder worms* or *cysticerci.* The ingrowing bud develops into a head or *proscolex* and a neck. Later proscolex and neck are everted. If man eats infested meat, the bladder worm is released from the "bladder" and the head, with its crown of hooks and four suckers, becomes attached to the wall of the intestine and there the tapeworm continues to grow as long as the head or scolex remains. In 1851, Kuckenmeister first discovered the hog or pork tapeworm, *Taenia solium,* also called the "armed" tapeworm on account of the 20 to 30 sharp hooks around the scolex. The adult stage is limited to man. The larval stage nearly always occurs in the hog but may be found in the dog. The hog tapeworm is rare in the United States but common in Mexico, Africa and Asia. In the United States the beef tapeworm, *Taenia saginata,* is more often found in man. It may be from 4 to 10 meters in length with as many as 2000 proglottids. Its scolex is about 1 to 2 mm. in

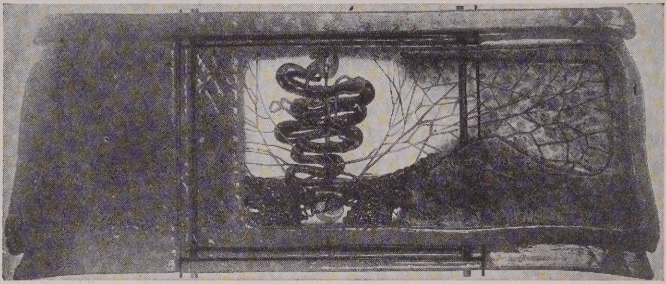

FIG. 152. — Structure of tapeworm proglottid. Photo of model. Courtesy of American Museum of Natural History.

diameter but differs from *T. solium* in that it has no hooks. The *adult stage* is found in man in the upper part of the small intestine, and the *larval stage* occurs in cattle. This parasite is found in every country. In Abyssinia, almost every adult harbors one of these unwelcome guests. "Measly" beef, containing cysts of *T. saginata*, has a mottled appearance.

Another tapeworm is common in dogs and cats and the intermediate hosts are fleas and lice. Yet another type is called the fish tapeworm. It is found in fish, and the intermediate stage occurs in small Crustacea on which fish feed. It is a common tapeworm found in man in Europe. Sometimes it causes serious anemia, greatly reducing the number of red blood cells.

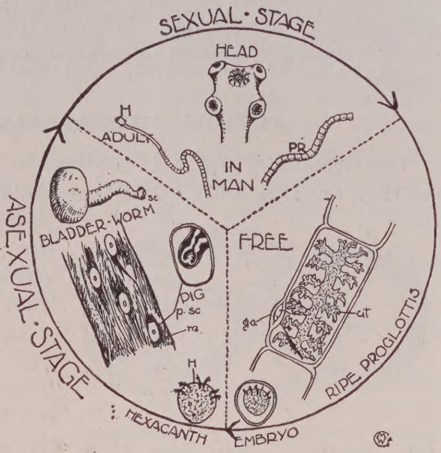

Fig. 153. — Life cycle of Taenia solium. From Thomson, *Outlines of Zoology*, D. Appleton & Co., reprinted by permission.

In the case of both liver flukes and tapeworms, the best protection is to eat *thoroughly cooked meat* and to drink *thoroughly boiled water*.

Summary of Platyhelminthes. They are Metazoans in which the body has further differentiated into the triploblastic condition characterized by ectoderm, mesoderm and endoderm. They possess bilateral symmetry. The digestive tract has but one opening which serves as a mouth and an anus. There is no special respiratory or circulatory system. The independent Planarian group exhibits characters nearer the line of evolution of higher types. Trematodes and Cestodes, on the other hand, are considered to be degenerate (specialized) offshoots of an original planarian-like ancestor. Degeneration is greater in Cestodes than in Trematodes and parasitism has correspondingly increased. The mesoderm in Platyhelminthes is a more or less dense tissue between ectoderm and endoderm. There is no body cavity, *i.e.*, *coelome* in it. But from the mesoderm has developed specialized systems of excretion and reproduction and also effective muscle tissue. From the ectoderm has developed a special nervous system at the head end of which is the beginning of a brain. The flame cell of the excretory system is a unique organ of excretion. Most flat-worms are monoecious. Although the flat-worms are comparatively simple, yet they are more highly organized than the Coelenterates.

PHYLUM — NEMATHELMINTHES

The Nematodes (Fig. 154) or 'thread-worms' or 'round-worms,' as they are sometimes called, are triploblastic, bilaterally symmetrical Metazoa, long, slender and cylindrical in form and worm-like in appearance. They exhibit *further specialization* over the flat-worms. The intestinal tract extends from the mouth throughout the length of the body and terminates in an *anus* at the posterior end. Thus the general body plan is a tube within a tube with a space or *cavity* between the intestinal tract and the body wall. In higher Metazoa the same general plan is found but the *body cavity* is brought about by the development of a space *within the mesoderm,* part of which is associated with ectoderm to form the body wall, while other mesoderm is associated with the endoderm to form the wall of the digestive tract. Such a *body cavity* is known as a *coelome.* In Nemathelminthes, a body cavity is present, but the mesoderm is associated with the ectoderm only, the digestive tract being composed only of endoderm. On that account the *body cavity* of round worms is *not* recognized as a *true coelome.* The ectoderm, mesoderm and endoderm develop into specialized cells, tissues and organs. The mesoderm, for example, develops longitudinal muscles just within the external ectodermal epidermis. The outer epidermis forms a cuticle of considerable thickness which may molt. The nervous system, formed from ectoderm, consists of a *nerve ring* around the diges-

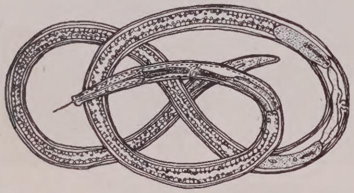

Fig. 154. — Xiphinema, the dagger Nematode. Injurious to plants, being able to thrust the *spear* into living tissues of roots. After Cobb — U. S. Dept. Agriculture.

tive tract near the anterior end, and from the nerve ring, nerves extend forwards and backwards. In the body cavity are well-developed excretory and reproductive systems. The animals are dioecious. There are no special circulatory or respiratory systems. The body cavity contains a fluid. Oxygen probably absorbed chiefly by the epidermal cells is taken up by this fluid and so distributed to other tissues bathed by it. Similarly food absorbed by the cells of the intestinal tract finds its way into the body-cavity fluid and it also bathes all internal organs, making possible the nutrition of all cells of the body. The intestinal tract is divided into regions indicating some degree of specialization. Nematodes are specialized forms occupying a place to one side of the evolutionary road to higher forms.

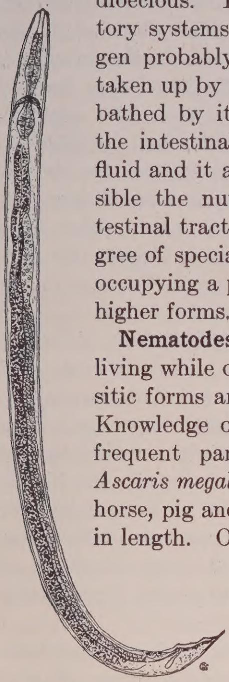

Fig. 155.—Rhabditis hominus (Kobayashi), from J. H. Sandground, *Journal of Parasitology*, 1911. Although found in feces, the author concludes that it is after all not a parasite in the human digestive tract but a free living coprophagous species.

Nematodes and Disease. Some Nematodes are free living while others are parasitic (Fig. 155). Some parasitic forms are free living during part of the life cycle. Knowledge of Nematodes is important because of their frequent parasitism in man and vertebrate animals. *Ascaris megalocephala,* often found in the intestine of the horse, pig and man, is a large type from six to ten inches in length. Other species of Ascaris sometimes infest the intestine of children, and are probably taken in with food or from playing around in dirt.

Trichinosis is a disease due to a parasitic Nematode, *Trichinella spiralis* (Fig. 156). Man is infested through eating raw or only partially cooked diseased pork. It is probable that the old Hebraic laws, prohibiting the eating of hogs which were regarded as 'unclean,' resulted from the observation that this practice caused *trichinosis,* and also tapeworm disease, *taeniasis.* Encysted larvae of Trichinae were first observed by Tiedemann in 1828. Rosenau states that probably from 1% to 2% of the hogs in this country are trichinous. Chandler found that infested sausage was the cause of one epidemic. It was later estimated that one pound of this sausage contained over 2,000,000 larvae of Trichina. In a piece of human muscle, from a man dying of trichinosis, a relatively greater number of worms was found. When man eats pork containing encysted larvae, the latter are released in the human intestine where the digestive juices break down the cyst walls. The larvae attain maturity in a few days. Copulation, between male and female worms, occurs in the intestine. The males die but the females containing fertilized eggs burrow into the walls of the intestine. In about a week, the eggs are embryos. They make their way into the intestinal lymphatics, thence to the heart, from which they are circulated about the body, lodging for further encystment in various tissues.

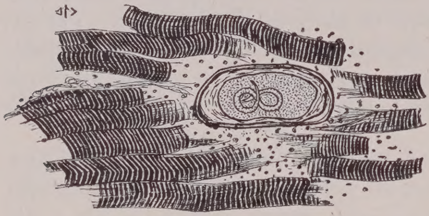
FIG. 156. — Trichina in muscle.

Should a sufficient number invade the muscles of respiration, death may result from paralysis of these muscles. Most of them lodge in the skeletal muscles near the tendons connecting the muscles to the bones. Muscular pains resembling rheumatism often result and 30% or more of the cases result in death. Rats and mice about slaughter houses are almost all infested. Trichinosis occurs in about 1% of the population of modern states. Possible parasitism is prevented by thoroughly cooking meat.

There are many species of the genus Filaria, a thread-like roundworm causing disease. *Filaria bancrofti* is the cause of nine human diseases. One of these is *elephantiasis*, in which parts of the body, usually the limbs, swell to an enormous size, in some cases a number of feet in circumference. In some tropical countries as many as 50% of the inhabitants are affected. The intermediate host is a mosquito. The worms migrate to the blood vessels of the skin at night, and so may be drawn into the stomach of a rapacious mosquito and, by this same animal, later injected into the blood system of some other person. Therefore the infested person is as dangerous to the community as is the mosquito.

Dranunculus medinensis is the 'guinea worm,' frequently causing disease in man in tropical Africa and Asia. The female locates in the subcutaneous tissue of persons who work in or about water. The worms can be felt under the skin. A skin ulcer develops so that the female worm can protrude her uterus to the outside to discharge a multitude of embryos whenever cold water comes in contact with the skin. The explanation of this peculiar reaction is that usually the embryos are thus discharged into water where a small crustacean, the water flea, *Cyclops*, is present in great numbers. The embryo worms enter the body of these crustacea to continue their life history and perchance are later taken into the intestinal tract of some person who drinks this water. Hypodermic injections of specific compounds such as chloroform in the tissue near the worm kills the latter, which is gradually absorbed and thus removed.

A nematode disease which still causes great economic loss in this country is the result of infestation with the American Hookworm, *Necator americanus*. Cases are found in numbers from Virginia to southern Brazil. Dr. Stiles states that 2,000,000 people in the southern part of the United States suffer from this disease. It was probably introduced here by negro slaves from Africa. Soil pollution is the great factor responsible for its continuance. Hookworms infest the intestinal tract. The eggs, liberated by the female worms into the intestinal tract, are voided with the feces. The eggs hatch and in a few days have developed into active larvae which feed on the fecal matter and soon become mature and able to infest persons properly exposed to them. Larvae live in warm, moist, filthy soil. A survey made between 1910 and 1915 revealed the fact that over a hundred thousand homes in the southeastern part of the United States had no facilities at all for the disposal of human excreta. This is the reason that the earth around these homes became polluted, and why the hookworm larvae remained alive. Persons walking barefooted (and this includes adults of both sexes as well as children) become infested by the larva entering through the skin. From the skin of the foot it gets into the blood stream, is carried to the heart, thence to the lungs, breaks through the lung tissue into the air passages, thence to the mouth. It is then swallowed and passes into the intestine to the wall of which it fastens itself, feeding on blood and causing digestive disturbances. The loss of blood results, not only in lowering resistance to disease, but also causes a great loss in efficiency. Injuries to the lungs render the victim liable to tuberculosis and to typhoid and other intestinal diseases due to lesions in the intestinal wall.

Waite says that "Wherever hookworm disease prevails, it creates one of the greatest menaces to physical, mental and economic progress." Only patient, continued and constant spread of the gospel of sanitation in infested districts can succeed in removing this form of human degeneracy, probably introduced here by the earlier institution of human slavery.

N. A. Cobb estimates that one acre of alluvial soil contains three billion Nematodes. He calls attention to the fact that "in countries where the wealth consists largely in stock, as in the western part of this country, in Australia and in the Argentine Republic, the monetary loss caused by Nematodes is always considerable, and sometimes very great." "A list of more or less serious human nematode diseases and ailments might be increased until practically half a hundred had been enumerated." "The common gallworm has been found infesting the roots of several hundred different species of plants, among them most of our cultivated crops, and causes an annual loss amounting to millions of dollars. There is another Nematode that has at times completely checked the growing of sugar beets in certain regions." "It may be estimated that more than 80,000 Nematode Species infest the forty-odd thousand species of Vertebrates." "Numerous as the parasitic species are, it is certain the number of species of Nematodes living free in soil and in water far outnumber them." "There must be hundreds of thousands of species."

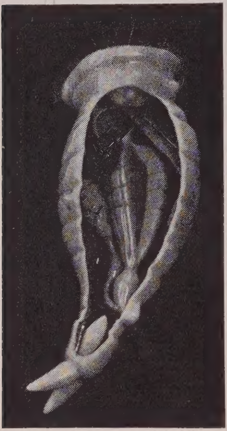

FIG. 157. — Rotifer or Wheel Animalcule. Photo of model. Courtesy American Museum of Natural History.

PHYLUM — TROCHELMINTHES OR ROTIFERS

This is a small group of microscopic forms found chiefly in fresh water. As an example (Fig. 157) we shall refer briefly to the Rotifer often seen by students when examining fresh-water cultures. The body has three portions, namely: (*a*) the head, which possesses a double row of circularly

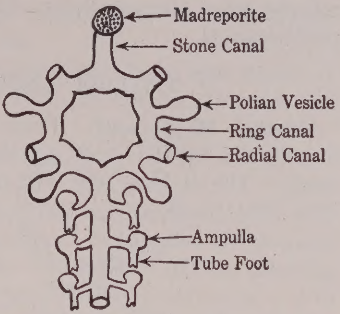

FIG. 158.—Diagram of plan of water-vascular system of starfish.

arranged cilia. The peculiar motion of the cilia gives the appearance of a rapidly rotating disc, on account of which these forms are often called "wheel animalcules." (*b*) The body is somewhat barrel-shaped and is often protected by a shell-like tube. (*c*) The tail is forked and has a gland which secretes a substance by which the animal is attached to objects. The digestive tract has a mouth, pharynx, stomach and intestine. An excretory system with flame cells is present. The nervous system is quite simple. The animal is dioecious. Some Rotifers can survive long periods of desiccation and some can live in the Arctic regions, where, although frozen for the greater part of the year, they become animated during the brief "summer" periods. Rotifers have a cavity between the digestive tract and the outer body wall, but many authorities claim that this is not a true body cavity, as we have already defined it.

The food consists of minute organisms which are swept into the mouth by the rotating oral cilia.

The body plan of some Rotifers is surprisingly like that of the *trochophore larva* of more highly specialized phyla. (See page 184.)

Trochelminthes are Metazoa that have a complete digestive tract with a mouth and anus. They are triploblastic, but as with the

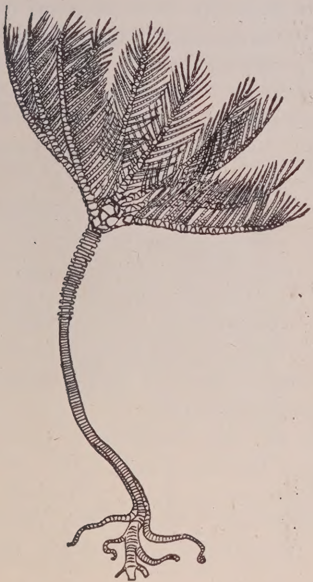

FIG. 159.—Pentacrinus—Sea-lily.

round-worms, the possession of a true body cavity or coelome is problematical.

PHYLUM — ECHINODERMATA[1]

General Morphology. These are triploblastic Metazoa with mouth, and digestive tract terminating in an anus and a *true body cavity.* The dividing egg (Fig. 303) forms in succession a morula (Fig. 303), blastula (Fig. 305) and gastrula (Fig. 305). Bilateral symmetry is established in early embryonic stages succeeding the gastrula, but *this soon becomes modified* so that the adult develops with a pronounced *radial* (*secondary*) *symmetry* adapted to more sedentary life, and slow locomotion is the characteristic result. Echinoderms are regarded as a specialized *offshoot* from the main line of evolution of the higher forms. They are marine forms with a five-rayed body, which, as a rule, has a calcareous exoskeleton in which are spines or plates. There is present also a special water-vascular system (Fig. 158) consisting of tubes containing fluid, and special organs, called tube feet, concerned in locomotion.

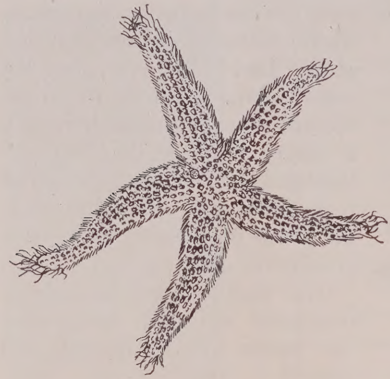

FIG. 160. — Asterias — starfish.

Classification

The phylum is divided into five classes and is made up of about 4000 species.

Class I. Crinoidea (Fig. 159) are feather stars which are attached (for part of the life period, at least) by a stalk to the sea bottom. The mouth surface and mouth opening are directed upward.

Class II. Asteroidea (Fig. 160) are the starfishes, so-called because the arms are prolonged like a five-rayed star. The oral surface is toward the substratum and the anus is above. The body axis is vertical and short. Starfishes are probably the most commonly observed Echinoderms. They move about slowly by means of their tube feet. Starfish appear in numbers on oyster beds, where they feed on the oysters.

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[1] From Greek, "spiny skin."

They have great powers of regeneration. If an arm is lost, it is replaced by a regenerated new one. In fact, at times, a new starfish will regenerate from a single arm. This power of regeneration is shared by all the Echinoderms. Oyster farmers cannot rid the beds of starfishes by cutting them in two and throwing the pieces back into the sea.

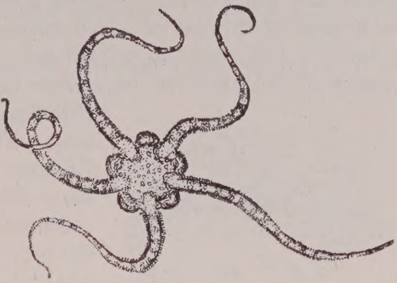
FIG. 161. — Ophiopholis.

Class III. Ophiuroidea (Fig. 161) or brittle stars resemble the Asteroidea, but the five rays are slender, elongated projections from a central disc. The animal progresses by the snake-like movements of its arms. They are the most numerous of the Echinoderms in number of species, and they feed on small animals or seaweeds.

Class IV. The Echinoidea (Fig. 162) have no arms. The body is globular, as in the sea-urchins, or disc-like, as in the sand dollar. The body is covered with spines, the basal end of each being attached to the body surface by a ball-and-socket joint. In some sea-urchins the body is covered with a thick investment of slender spines, while in others there are but a few thick and longer ones. In some, the tips of the spines are poisonous. Sea-urchins are widely distributed in salt waters near the shore. The gonads are used as food by some maritime people.

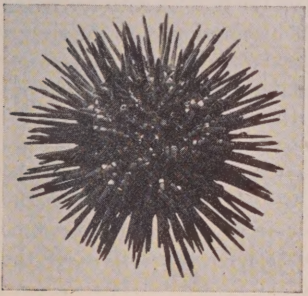
FIG. 162. — Sea-urchin. (Am. Mus. Nat. Hist.)

Class V. Holothuroidea (Fig. 163) or Sea-cucumbers are Echinoderms in which the body wall is soft. There are no spines or tube feet. The body axis may be elongated, giving to the animal a worm-like appearance. The animal rests upon its side with the mouth and anal ends raised somewhat above the main body mass.

The mouth end is provided with tentacles. Radial symmetry is still present. Internal organs are homologous with those of other Echinoderms. The body wall is very muscular. Under certain conditions a sea-cucumber will evert its internal organs. Some have the power of secreting a substance which is discharged as a mass of threads in which enemies are entangled and made helpless. Although the animal may lose its internal organs, it possesses the power to regenerate new ones. In the Far East Holothurians are dried and used for food. This is the " trepang " of the Chinese. Aristotle originated the name Holothurian.

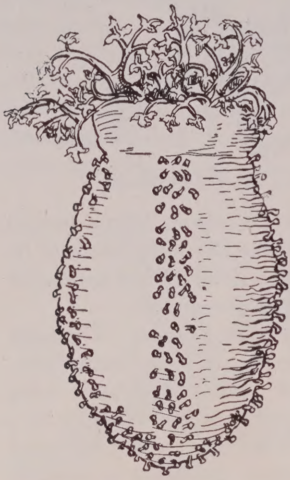

Fig. 163. — Pentacta.

Summary of Echinoderms. They are very old forms, having been well established in the Cambrian Period. They have, apart from the general characteristics noted at the beginning of this chapter, *little in common with other groups of animals.* It has been suggested that their ancestors were worm-like forms with bilateral symmetry and that they later developed *secondary* radial symmetry adapted to a life on the bottom with restricted powers of locomotion. All the groups of Echinoderms have a free-swimming, bilateral larval form. The intestinal tract of the larva has a mouth, oesophagus, stomach, intestine and anus. From the digestive canal two pouches are evaginated to develop into the water-vascular system and the coelome. A larva somewhat similar to this is present during the life history of Balanoglossus, a Chordate. On this account, some zoologists regard Echinoderms as ancient relatives of the Chordata.

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CHAPTER XI

ANNELIDA

PHYLUM — ANNELIDA

General Characteristics. The Annelida constitute a distinct phylum of worm-like forms. A study of their embryology indicates stages similar to those of lower forms such as Hydra and Planaria. Thus, the animal begins as a fertilized egg which undergoes cleavage (Fig. 303) and passes through a morula, blastula (Fig. 305) and gastrula stage. Mesoderm appears, so that Annelida are triploblastic animals. The body is bilaterally symmetrical and has antero-posterior and dorso-ventral differentiation. The intestinal tract extends from the mouth to the anus. *Within* the mesoderm is developed a true body cavity or coelome. This differs from that present in Nematodes because it is developed *in* the mesoderm; *i.e.*, the body wall is composed of structures developed from ectoderm and mesoderm, while the intestinal tract is developed from structures arising from mesoderm and endoderm. A similar *coelome* or *true body cavity* is formed during development of higher animal phyla. Within the coelome are specialized organs of circulation, excretion and reproduction.

Metamerism. The name Annelida or Annulata refers to the fact that the body is composed of a number of serially repeated portions called segments or metameres. They are also called somites, a word derived from the Greek "soma," meaning "body." Segmentation or *metamerism* is characteristic of most of the higher phyla and is thought to be of considerable evolutionary significance. Metamerism is not merely a superficial character but also finds expression in serially repeated units of the muscular, vascular, excretory and nervous systems.

Earthworm — Study of a Type

Lumbricus, a common earthworm, is suitable for a detailed study of structure of the Annelids. It is important to become familiar with the anatomy of an animal of this group because it is an introduction to the study of the morphology of more specialized animals.

External Features (Fig. 164). The worm is purplish brown in color and has about 160 segments, the number varying. At about the thirty-first, and extending backward for a few segments, is a swollen part called the *clitellum.* On each segment are *four pairs* of short bristle-like *setae.* These are locomotor organs and are of great use when the worm is in its burrow. On the ventral side of most segments or *somites* are the two openings of the paired *nephridia* or kidneys. In the grooves between the ninth and tenth, and tenth and eleventh somites, are two pairs of minute openings of the internal *seminal receptacles.* On the floor of the fourteenth somite are the two openings of the *oviducts.* On the floor of the fifteenth segment are the two openings of the *vasa deferentia,* ducts carrying sperm from the testes.

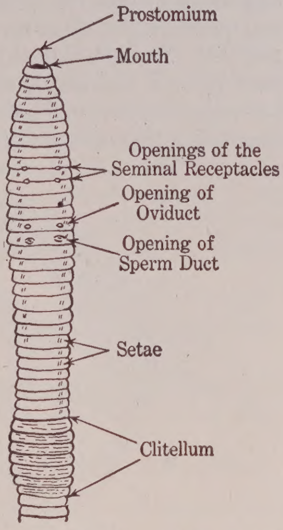

Fig. 164. — Diagram of ventral surface of anterior portion of an earthworm. Openings smaller than in diagram.

At the front end of the worm is an incomplete segment, which forms a lip-like proboscis over the mouth. It is the *prostomium.* Perforated partitions extend from the body wall to the intestine. These are *septa* and appear as the ring-like lines or *annuli* on the surface, separating one segment from another.

Body Wall, Coelome and Intestinal Wall (Fig. 165). On the outside of the body is a thin, non-cellular layer, the cuticle, in which are the various external openings referred to in the preceding paragraph. Within this and derived from ectoderm is the epidermis, composed of columnar-shaped cells. These form a thin membrane or epithelium covering the internal tissues. Some of the epithelial cells are *gland* cells which keep the body surface moist while others are *sensory* and therefore irritated by external stimuli, but most cells are protective. Within the body-wall epithelium is a layer of *circular muscle* and within this is a thicker layer of *longitudinal muscle.* Both muscle layers are composed of contractile cells derived from mesoderm. The cells of the circular layer occur at right angles to the longitudinal axis of the body, while those of the longitudinal layer run lengthwise of the body. The lengthening and shortening of the body is accomplished by the action of these muscles. Examination of a living worm reveals contraction waves passing over the worm, and the body at a given point is now extended and now contracted. Within the layer of longitudinal muscle is a thin cellular epithelial membrane called the *peritoneum,* forming the internal lining of the body wall. The *septa* are covered on each surface with *peritoneum,* and these two layers inclose a thin layer of muscle and connective tissue. The intestinal tract is lined with *columnar epithelial* cells derived from endoderm. The coelomic surface of the intestine is composed of a layer of special peritoneal cells called *chloragogue cells.* They extend into a fold of the intestine along the dorsal mid-line, forming the core of the *typhlosole.* Between the chloragogue cells and the internal epithelium is a thin layer containing muscle cells and connective tissue. Body wall, septa and intestine are well provided with blood vessels and nerve fibers.

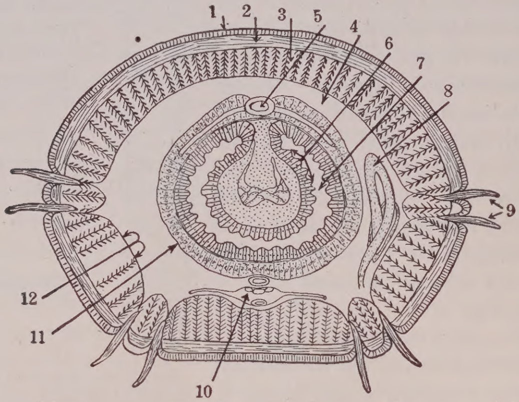

Fig. 165. — Diagram of cross-section of body of earthworm. 1 — Epidermis; 2 — Circular muscles; 3 — Longitudinal muscles; 4 — Body cavity or coelome; 5 — Dorsal blood vessel; 6 — Typhlosole; 7 — Intestinal cavity; 8 — Nephridium; 9 — Setae; 10 — Ganglion; 11 — Chloragogue cells; 12 — Somatic peritoneum.

Digestive Tract (Fig. 166). The mouth opening or buccal cavity leads into the *pharynx*, a spindle-shaped tube, largely muscular and functioning in the swallowing of food. Behind the pharynx is the *oesophagus*, a thin-walled tube concealed by adjacent organs. The oesophagus extends from about the sixth to the fourteenth segment. Posterior to the oesophagus is a large saccular, thin-walled *crop*, extending from about the fourteenth to the seventeenth segment. Posterior to the crop is a large pouch, the thick, muscular *gizzard*, extending from the seventeenth to the nineteenth segment. Posterior to the gizzard is the smaller tubular *stomach-intestine* which extends throughout the rest of the body to the *anus*. In the dorsal wall of the stomach-intestine is infolded a long ridge called the *typhlosole*, which increases the internal surface of the intestine and contains cells which probably function in digestion and absorption. Small *calciferous glands* occur along the sides of the oesophagus near the rear, and secrete into it an alkaline fluid which neutralizes acid food. The earthworm feeds at night, eating earth with small bits of plant and animal matter. Food passing into the crop is softened there, after which it is passed into the gizzard, where the muscular action of the gizzard walls grinds up the food between the grains of sand which are eaten with the food. Thence it passes to the stomach-intestine, where different types of enzymes simplify it into compounds which can be absorbed into the cells of the intestine and probably thence into the coelomic fluid and blood vessels. Undigested material is discharged posteriorly from the *anus*.

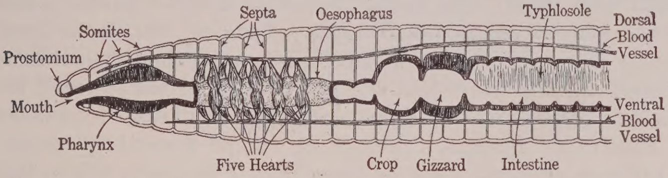

FIG. 166. — Diagram of sectional view of anterior portion of the earthworm.

Circulatory System (Fig. 166). The earthworm (Annelid) is the first animal we have studied which possesses blood and blood vessels. There are a few long trunk blood vessels from which branches extend to the organs in their vicinity. There are five of these main trunks: first, the *dorsal vessel*, which runs along the upper surface of the intestinal tract; second, the *ventral vessel*, which is underneath the intestine; and third (Fig. 165), the *subneural vessel,* located underneath the nerve cord and two small *lateral neural vessels* one along each side of the nerve cord. The lateral branches of these upper and lower main trunks connect with each other in various ways by means of branches terminating in a smaller network of capillaries located in the tissues, thus forming a complete system. In the neighborhood of the oesophagus, on each side, are five pairs of large vessels (Fig. 166) which connect the dorsal vessel with the ventral vessel. These are called the "hearts." The dorsal vessel and the hearts are contractile. Valves in the dorsal vessel and in the hearts insure the flow of blood forward in the dorsal vessel, and a great part of it is carried down by the "hearts" to the ventral vessel. In general, the blood flows toward the rear in the ventral vessels but forward in the dorsal vessels. The nervous system is especially well supplied with blood. The blood consists of a liquid *plasma* which contains a few minute *colorless cells.* The red color of the blood is due to the presence of a protein-iron compound called *hemoglobin,* which is dissolved in the plasma and has the power of absorbing oxygen from the air and carrying it to all cells of the body.

Respiratory System. There is no special respiratory system. Capillaries are near enough to the surface of the moist skin so that the hemoglobin of the blood may absorb oxygen, which is thus circulated throughout the body. The worm would die from oxygen starvation if the skin dried up. Carbon dioxide is discharged from the circulating blood through the skin.

Excretory System (Figs. 165–167). A pair of excretory organs or *nephridia* occur in most somites. A *nephridium* is a coiled tube, located in the lateral lower portion of the coelome between the intestine and body wall. The anterior end is a ciliated funnel called a *nephrostome.* From the nephrostome, the tubular kidney passes back through the septum *behind the nephrostome* into the rear somite where most of the kidney lies. In this somite the kidney has several coils and its posterior end opens to the outside on the floor of this somite. Part of the coiled tube is lined with cilia. The cilia create a current which draws fluid into the nephridium from the contents of the body cavity. Some part of this fluid is waste matter. Gland cells, forming the body of the tubule, probably also abstract waste matter from the blood capillaries which closely invest the tubule. Within the tubule, the current, created by the cilia, transports these wastes out through the excretory pore.

Nervous System (Figs. 165 and 167). In the earthworm there is a centralization of nerve cells. Underneath the intestine is a long white cord, the ventral nerve cord. In each segment the cord presents a swelling, a *ganglion.* Under the pharynx, the nerve cord ends with the *subpharyngeal ganglion.* From the sides of this, lateral cords extend up on either face of the front of the pharynx ending above in the *bilobed suprapharyngeal ganglion* or *brain* located in the third somite. From each ganglion, nerves extend out into adjacent organs and tissues.

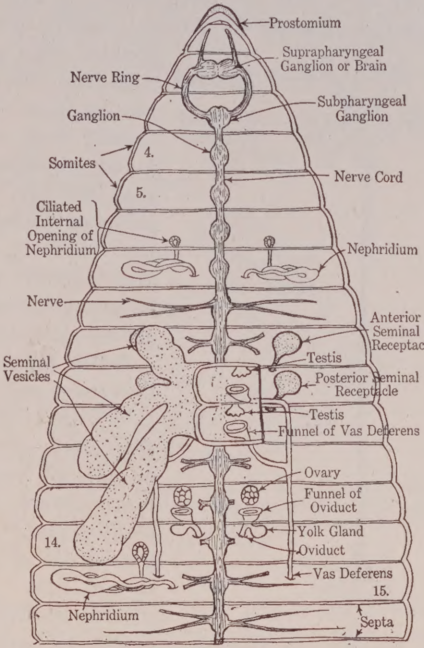
Prostomium
Suprapharyngeal Ganglion or Brain
Nerve Ring
Subpharyngeal Ganglion
Ganglion
Somites
4.
Nerve Cord
5.
Ciliated Internal Opening of Nephridium
Nephridium
Nerve
Anterior Seminal Receptacle
Testis
Seminal Vesicles
Posterior Seminal Receptacle
Testis
Funnel of Vas Deferens
Ovary
Funnel of Oviduct
Yolk Gland
14.
Oviduct
Vas Deferens
15.
Nephridium
Septa

FIG. 167. — Anatomy of earthworm. (Modified from model by C. H. Ward.)

A nerve cell (Fig. 168) consists of three parts; first, a larger, cell-like part or *cyton,* which contains cytoplasm and the nucleus; second, a series of short, branching roots or *dendrites,* and third, the *axone* or thread-like process which serves mainly to conduct the impulses. The nerve-cell body is a sort of relay station or battery. The nerve-cell axones are the "wires" along which the nerve "current" runs. Dendrites of one nerve cell "pick up" impulses from the terminal branches of the axone of another nerve cell with which the first is associated. The connection between the two is called a *synapse.* The ganglia noted above are aggregations of nerve-cell bodies and their connecting or synaptic branches. The nerve cord is a linear arrangement of ganglia and connecting nerve axones. The nerves which extend to the tissues from the ganglia are bundles of axones. The brain of higher forms is a larger and more complex aggregation of nerve cell bodies and processes.

There are three types of nerve cells. First, those that conduct impulses from the sensory surface to the ganglia of the nerve cord. Such nerve cells are called sensory or *afferent* because they convey impulses, aroused by external stimuli, toward the central system. Second, other nerve cells conduct impulses from the ganglion out to a muscle, causing it to contract, or to a gland, causing it to secrete. They are *motor* or *efferent* nerves. Third, within the cord are also *association* cells whose processes connect cells in one ganglion with those of another ganglion. By *nerve impulse* is meant some sort of physico-chemical change which progresses along the nerve fiber.

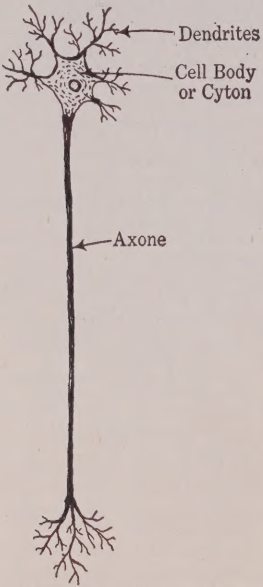

Fig. 168. — Nerve cell or neuron.

Reflex Mechanism. A ganglion with its sensory and motor nerve cells constitutes part of a simple reflex apparatus (Fig. 169). An external stimulus affects an afferent nerve cell which has a part terminating in a sensory cell in the skin of the worm. In some cases a peripheral process of a *sensory nerve cell* begins in the skin. This portion of a reflex mechanism which receives the stimulus is called a *receptor*. The receptor sends an impulse into the ganglion. Here it is transferred to a motor cell. This cell is called an *adjustor*, because it adjusts or may modify the incoming impulse. The muscle aroused to action by the efferent impulse of the adjustor cell is called an *effector* and is the terminal part of the reflex apparatus. The movements and activities of the earthworm are simple reflexes or combinations of them. The earthworm is sensitive to various forms of external stimuli. Special epidermal cells of the skin, particularly toward the anterior and posterior ends of the worm, form sense organs which are connected with afferent nerves. These two portions of the body are especially sensitive.

Reproduction System and Reproduction (Fig. 167). A pair of *ovaries* is located on the anterior septum of the thirteenth somite. Behind them in the same segment are the funnel-like openings of the short *oviducts* which open to the outside of the body on the floor of the fourteenth somite. In the ninth, tenth, eleventh and twelfth segments are large sac-like organs. These sacs are known as the *seminal vesicles.* They serve to store sperm. Spermatozoa are secreted by two pairs of *testes.* There is one pair in the tenth and one pair in the eleventh segment. One pair of sperm funnels in the tenth and one pair in the eleventh segments, each just behind the testes, are connected by branch tubes which join and form the long tubular *vasa deferentia.* They convey sperm from the seminal vesicles to the outside of the worm. In the tenth segment is a pair of *sperm receptacles* and in the eleventh segment is another pair also. They do not communicate with the body cavity but only by pores to the outside of the body. These openings have already been located.

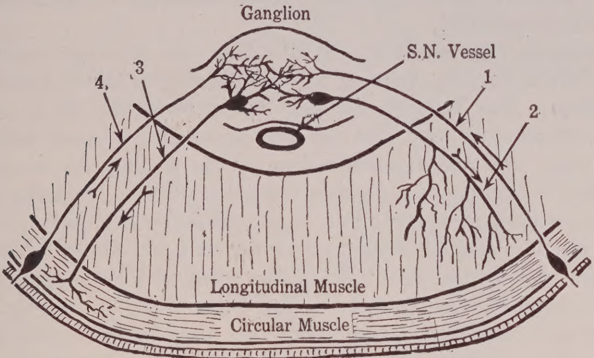

FIG. 169. — Diagram of reflex mechanism in earthworm. 1 and 4 — Sensory neurons (Receptors) 2 and 3 — Motor neurons (Adjustors), Muscles are effectors. An impulse coming in over 1, may *go out* over 2 or 3 or both and *may* extend in the nerve cord forward and backward. S. N. — Subneural Vessel.

In the breeding season, two worms come together with the heads pointing in opposite directions. The ventral surface of that part of the body from the clitellum forward (*i.e.*, approximately segments 37 to 1) of one worm is in contact with a similar portion of the other worm. Mucus is freely secreted from glands in the skin of these two regions. The mucus hardens and forms a *common tube* about both worms. The body wall and the mucus also form *temporary ducts* for the passage of spermatic fluid. This is pumped out of the openings of the *vas deferens* of each worm, down along the temporary ducts to a cavity under the clitellum of the same worm. This space is just opposite the openings of the sperm receptacles of the other worm. Sperm fluid is sucked into the receptacles. There are two pairs of temporary sperm ducts. They prevent self-fertilization. After exchange of spermatozoa, the worms separate.

Later on, eggs are laid. At this time the clitellum secretes a fluid which hardens, forming a band-like ring or *girdle* about the clitellum. The worm works this girdle forward. As it passes the oviduct openings, eggs are discharged into a space between the body wall and the inner face of the girdle. As the girdle passes the opening of the sperm receptacles, sperm from the other worm are discharged among the eggs. Thus *fertilization* is effected. The girdle continues being worked forward and finally is slipped off the front end of the worm. The front and rear edges of the girdle come together forming a closed sac or *cocoon* in which development continues. The cocoons are placed a few inches below the surface of the earth. It is said that only one worm hatches from the cocoon in the case of the species, *Lumbricus terrestris*. It is small and immature at the time of hatching.

The fertilized egg divides, passing through a blastula stage and later a gastrula stage (Fig. 170). This elongates somewhat and a mouth is formed by an ingrowing tube at the blind end of the gastrula. The solid mesoderm which has formed between the ectoderm and endoderm develops spaces in it. These spaces are the embryonic beginnings of the coelome. As the worm grows the body cavity increases also. The mesoderm partitions between the coelomic segments become the septa, later.

Behavior. The earthworm exhibits very definite responses to stimuli of various sorts, such as bright light, chemical and mechanical stimuli. The body attempts to draw away from irritating objects. Some stimuli, such as food, may produce a positive reaction. Experiments indicate that the earthworm is not altogether a simple machine. Under certain circumstances it exhibits an ability to learn by experience and to remember for a short time. In an experiment by Yerkes, an earthworm was set free on the surface of earth which filled a box. Avoiding the light, it crawled here and there, finding one or the other of two burrows, one of which contained a pair of electrodes. If it started down the electrified burrow, it received a slight shock which caused it to withdraw. It crawled around and tried the burrows again and again. After a certain number of trials it "learned" to crawl immediately into the "safe" burrow when released. In other words, it had the nervous organization which enabled it to profit by experience.

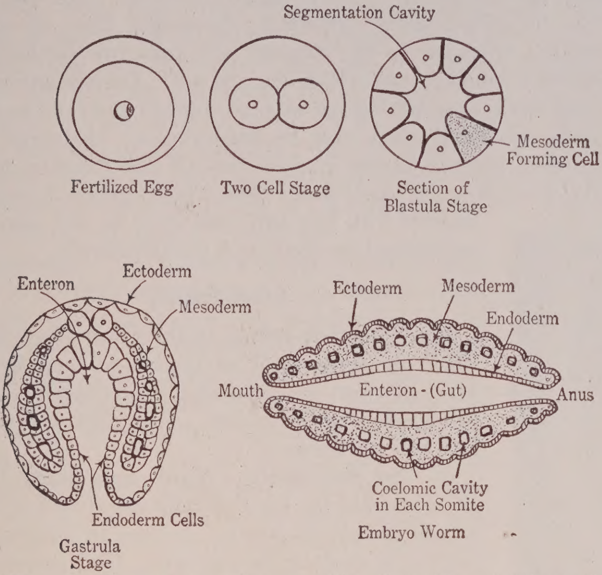
Segmentation Cavity
Mesoderm Forming Cell
Fertilized Egg
Two Cell Stage
Section of Blastula Stage
Enteron
Ectoderm
Mesoderm
Endoderm Cells
Gastrula Stage
Ectoderm
Mesoderm
Endoderm
Mouth
Enteron - (Gut)
Anus
Coelomic Cavity in Each Somite
Embryo Worm

FIG. 170. — Development of earthworm. After Sedgwick and Wilson, *General Biology*, Henry Holt and Co. Reprinted by permission.

Regeneration. The earthworm possesses great powers of regeneration. A large piece removed from the front end of the body will regenerate a new tail at the hinder end, and in time become a completely organized worm. Such experiments suggest the persistence of asexual powers of reproduction among these forms, or in other words, regeneration is related to asexual reproduction so common in lower forms.

Economic Importance. Charles Darwin studied carefully the effects of earthworms on soil. His book on the " Formation of Vegetable Mold through the Action of Worms " was written after studies extending over forty years. He estimated that a certain garden patch contained a population of 50,000 worms to the acre. In forming burrows, the earthworm ingests the earth, which is carried into the alimentary canal. Whatever food there is, is digested and absorbed. The undigested residue, with the soil particles, is passed along and finally discharged from the anus around the entrance to the burrow. In this way earthworms slowly and in small amounts turn over the soil. Darwin estimated that eighteen tons of subsoil per acre are spread out to sun and air (and thus sterilized) every year by earthworms. Moreover, the formation of burrows carries air into the soil and moisture is retained more easily. In thirty years' time, a stony field was entirely covered with new turf, and most of this was accomplished by the action of earthworms.

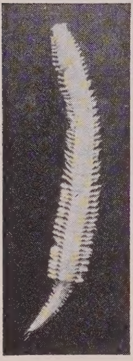

FIG. 171. — Nereis. Note regenerating posterior end. (Photo by Schechter.)

Classification

Most Annelids belong to the Class *Chaetopoda.* They are fresh-water or marine or land forms. Most of them are segmented; they also have appendages on the segments. This class is divided into two subclasses:

(*a*) **The Polychaeta.** *Nereis*, an example (Fig. 171), is called the sand or clam worm and is used as bait by sea fishermen. It lives in burrows in sand or mud along the seashore. Nereis possesses lateral flat appendages called parapodia (alongside feet). The parapodia serve as propelling organs and as gills. Nereis is, in some respects, more highly differentiated than Lumbricus in that there are two pairs of eyes, and tentacles and biting jaws at the head end. Many Polychaets reproduce *asexually* by budding. In others there are two regions of the body, an anterior sexless and posterior sex region. The posterior sex region separates from the anterior in which event the anterior part produces another posterior sex region again. Polychaeta are dioecious.

(*b*) **The Oligochaeta.** These are mostly fresh-water or terrestrial forms which are hermaphroditic. They have neither parapodia, tentacles nor well-defined sense organs, although the front end of the body is very sensitive to external stimuli. There are over twice as many Polychaets as Oligochaets. Lumbricus is an Oligochaet.

The **Hirudinea** or leeches comprise another interesting group. These are found in fresh water; and have a body form resembling flat-worms, but are segmented. Some are predaceous, eating other Annelids, snails, etc. Some of them are external parasites, sucking blood of aquatic Vertebrates. In the blood-sucking leeches (Fig. 172) the animal liberates a secretion which prevents the coagulation of the blood. Extracts of the desiccated bodies of this leech contain such anti-coagulating material. This is known in medicine as *hirudin,* and is employed in certain cases in which the non-coagulation of the blood is an essential part of medical treatment.

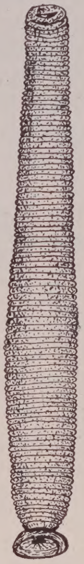

FIG. 172.— Hirudo, leech.

Summary. The Annelids exhibit three theoretically important features which relate them to higher groups. *First — Coelome.* The true body cavity between intestine and body wall is lined throughout with tissues which develop from mesoderm. It is filled with coelomic fluid containing dissolved food compounds absorbed from the intestinal tract, and oxygen; also wastes of metabolism such as water, carbon dioxide and nitrogenous compounds. Movements of the body circulate the coelomic fluid, thus enabling tissues bathed by it to absorb foods from it and to discharge into it wastes to be excreted by the nephridia located in it. But far more important is the fact that from mesoderm are developed organs of circulation, excretion and reproduction — all of which are afforded a space in which to develop. As to *absence* or *presence* of coelome, Metazoa are divided into (*a*) the *Acoelomata,* including the Porifera, Coelenterata, Platyhelminthes; and (*b*) *Coelomata,* including Annelida, Echinoderms, Mollusca, Arthropoda and Chordata. Nemathelminthes and Trochelminthes are doubtfully assigned to one group or the other for the reason given in the previous chapter.

Second — Metamerism. Segmentation is very characteristic of (*a*) Annelids, (*b*) of the great group of the Arthropoda and (*c*) of the Chordata as well. It has been *suggested* that the metameric body of such forms as Annelids, Arthropods and Vertebrates evolved by a *linear integration* of *separate individuals.* Some systems, such as that of digestion, have lost almost all traces of ancestral conditions, while others, like the ganglionated nerve cord, still exhibit evidences of metamerically repeated parts, *i.e.*, formed by an end-to-end fusing of nerve cords of hypothetically ancestral individual animals.

The *development* of metamerism in the *individual* has been worked out by the embryologist, but the *evolution* of metamerism is still quite theoretical. The embryological evidence is opposed to the "end to end" theory just indicated.

Third — Trochophore. This name is given to a larval stage occurring in the development of some primitive Annelids. As shown by Fig. 173 the trochophore larva is somewhat bi-convex or bi-conical in shape. Around the equatorial region is a band of cilia and the larva is free-swimming. At one place on the ciliated margin is the mouth which leads into an oesophagus, stomach and intestine which ends in an anus at the tip of the more elongated "cone." At the opposite apical end is a sensitive "eye-spot." The trochophore larva also has a pair of simple nephridia.

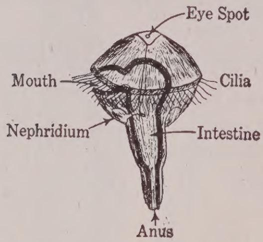

FIG. 173. — Trochophore larva of Polygordius. From Newman (after Whitman), *Outlines of General Zoology*. Copyright 1924, by The Macmillan Co. Reprinted by permission.

Certain marine worm-like animals related to the flat-worms have a larva similar to this. The Trochophore also resembles certain *adult* Rotifers. Moreover, most Mollusks, in their development, pass through a trochophore phase. All these facts are interpreted as embryological evidence which indicates the phylogenetic (evolutionary) relationship of Flat-worms, Rotifers, Annelids and Mollusks.

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CHAPTER XII

MOLLUSCA

PHYLUM — MOLLUSCA

General Characteristics. The word Mollusca is derived indirectly from a Latin word " molluscus," meaning " soft," referring to the soft body of these animals, which possess no true skeleton although most of them form a shell, chiefly calcium carbonate. The Mollusks are a group of triploblastic Metazoa, persisting from the Cambrian Period when they were already prominent. They are still represented by about 60,000 species divided into a number of groups which have little superficial resemblance to one another, but are all called Mollusca on account of common characteristics revealed by detailed embryological and anatomical investigations. They are not segmented as are the Annelids nor is the embryonic coelome prominent in the adult. For the most part they evolved a highly specialized body plan peculiar to themselves and are not easily connected to other phyla.

We study them because they are undoubtedly biologically successful and because they are of great economic importance. Two general characteristics are evident: first, a muscular organ of locomotion called a *foot*, which varies in form in different classes, and second, the *shell*. The shell encloses the internal organs. A membrane called the *mantle* secretes the shell and is found next to the inner surface of the shell. Some Mollusks have neither shell nor mantle. A simple type of heart is present. The respiratory system consists of membranous-like plates of soft tissue in the mantle cavity on either side and called the *gills*. In many land forms the mantle serves as a respiratory organ. The *eyes* are especially well developed in some groups. A complex digestive gland called a liver is connected with the digestive tract. They comprise the largest group outside the phylum Arthropoda. Common examples are the clam, snail, oyster, scallop, squid and octopus.

Unio, a Type. Unio (Fig. 174) is a fresh-water mussel and lives in the bed of lakes and streams. Carbonate of lime must be present in the waters inhabited by the mussel. It can *move* from place to place and *burrow* with its *foot* (Fig. 175), which it can project forward between the valves, anteriorly. From the opened shell at the posterior end extend two tubes called the *incurrent* and *excurrent siphons.* Water with oxygen and food is drawn *into* the ventral or *incurrent* siphon and wastes of metabolism are passed out of the dorsal or *excurrent* siphon. The shell consists of two *valves,* hinged together dorsally by an elastic ligament. The concentric lines on the surface of the valves indicate growth increments and mark former positions of the edge of the mantle. The hump or *umbo* near the anterior *dorsal* region marks the size of the *young* clam. The shell is made up of three layers: (*a*) an outer, thin and horny layer, protective in nature; (*b*) a middle layer of crystals of calcium carbonate and (*c*) the inner lining, the nacreous layer, composed of a number of thin layers formed by the entire outer surface of the mantle. This layer produces a prismatic effect on light and is called *mother-of-pearl.* Extension of shell is produced by secretions of mantle cells along the outer margin of the mantle folds along the edges of the valves. The valves are held together by two transverse muscles (Fig. 176). These are located near the dorsal surface at each end and are called the *anterior adductor* and the *posterior adductor* muscles. As the animal grows they are found farther and farther apart. The mantle folds are in contact with the inner surface of the valves. Enveloped by the mantle folds are the gills and the visceral mass composed of the foot, digestive tract, heart, blood vessels, blood, kidneys, nervous system and reproductive organs.

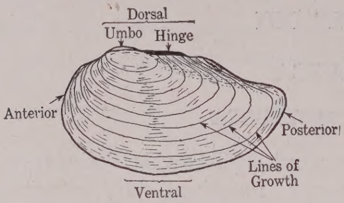

FIG. 174. — Unio.

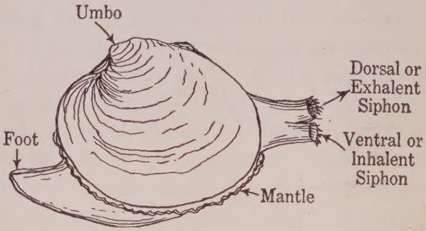

FIG. 175. — Venus mercenaria, hard-shell clam.

Mussels are usually dioecious, that is, the sexes are separate. The reproductive glands are located in the visceral mass. The spermatozoa are carried out through the dorsal siphon of the male

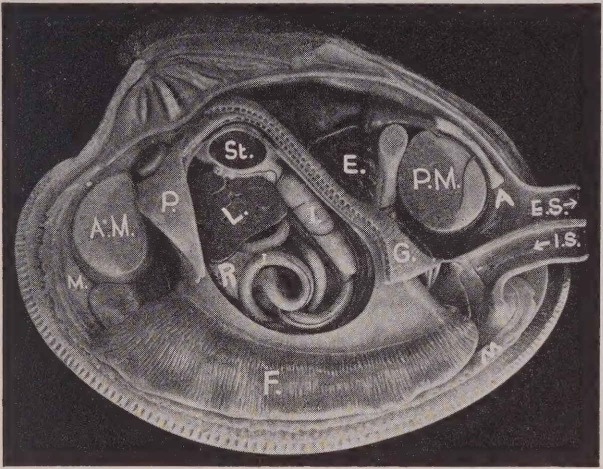

Fig. 176. — Anatomy of Venus, the hard-shell clam. E. S. Exhalent siphon; I. S. Inhalent siphon; A. Anus; P. M. Posterior adductor muscle; A. M. Anterior adductor muscle; P. Palp; L. Liver; St. Stomach; R. Gonad; I. Intestine; G. Gill; F. Foot; M. Mantle; E. Excretory Gland. (From photo of model. Courtesy American Museum Natural History.)

and are drawn into the ventral siphon of the female. The eggs pass out of the genital aperture and are caught by the gills at many places. Here they are fertilized by the sperm. The fertilized egg undergoes cleavage and passes through a blastula and gastrula stage.

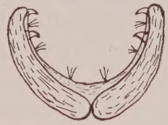

Fig. 177. — Glochidium of Lampsilis alata, a fresh-water mussel. (Lefevre and Curtis, U. S. B. F.)

A unique feature is the development of a larva called a *glochidium* (Fig. 177). This is a small bi-valved form. A relatively strong adductor muscle closes the valves under conditions to be stated presently. Development proceeds as far as the glochidium stage in the gills of the female Unio. The larvae are discharged into the water in the early autumn. If water containing glochidia is taken in by a fish, many of the glochidia become attached as the water containing them passes the gills in respiration. Contact with the fish gill stimulates the muscles of the glochidia to contract and the valves close, holding the larvae in place on the gill. Wherever the fish travels, there travel the young Unios. The larvae remain parasitic on the fish gill until the adult Unio organs develop. Then the young mussels are freed. Bi-valve Mollusks have poorly developed organs of locomotion. The interposition of the glochidium stage attached to the body of a form like a fish which travels far and wide in search of better feeding or breeding grounds is favorable to the Unio since it may be set free in a favorable locality not yet occupied by Unios.

Classification

There are a number of classes of *Mollusca*. Among these are the Gastropoda, the Pelecypoda and Cephalopoda.

Class I. The Gastropoda number about 49,000 known species. They are commonly called snails (Fig. 178), which name is applied to the aquatic marine forms as well as to the land forms. The body is asymmetrical, with a spirally coiled shell. This spiral twisting causes a rearrangement of the internal organs and the loss of the left member of paired organs. In most snails the spiral turns to the right. The head bears tentacles and eyes and there is a foot on the ventral side of the body. Most snails are *oviparous*, laying their eggs in various kinds of egg cases, and most of them are aquatic.

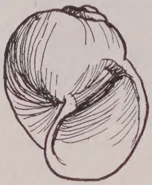
Fig. 178. — Natica, a marine gastropod.

Class II. The Pelecypoda (Fig. 179) (*Lamellibranchiata*) number about 11,000 species living today. These are symmetrical bi-valved Mollusks without any head. The anatomy of the Pelecypoda is indicated by the description of Unio. They are all aquatic and mostly marine, many being found in shallow waters. In the Pacific Ocean is found a giant clam, *Tridacna gigas*, sometimes over three feet long and weighing 250 pounds. On the other hand, the small, fresh-water *Pisidium* is but a few millimeters in length.

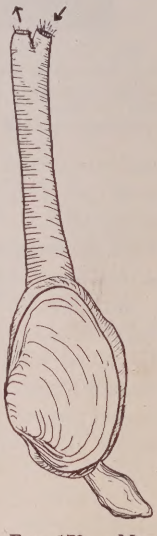
Fig. 179. — Mya arenaria, soft-shell clam.

Pelecypoda are of great economic value. The oyster fishery is a leading sea-food industry.

Taking of oysters from natural beds and placing them in waters where they would be more protected and more available was practiced in Italy, long before the founding of the Roman Empire. It is also said that oysters were shipped to Rome from England in the days of the Caesars. There are oyster fisheries today in Europe, Asia, Africa, Australia and the Americas. In the United States most of the oysters are obtained along the seashore from Massachusetts to Texas. Oyster farming is most successfully practiced in an artificial way in France. It cannot be said that the oyster is of high food value although it does contain some protein and considerable glycogen or animal starch. It is easily digested and has an appetizing flavor.

The sexes are separate in the Atlantic coast oyster. The female develops annually millions of eggs, which are microscopic in size, while many more sperm are produced by the males. Discharged into the water in the spring, when the water temperatures are rising, the sperm swim about until they come in contact with an egg and fertilization takes place. In a few hours a swimming embryo is developed. The shell gradually forms, and by the time the animal is fully surrounded by the valves, the yolk is all used up. At this time, from one to two days after fertilization, the animal becomes a larva, in which condition it swims about after food. The left valve now gradually grows more rapidly than the right, and in about two weeks, still very small, the young oyster attaches itself to an old shell or rock, becoming the " set " or " spat " stage. In about four or five years, it is marketable. Oyster fishermen, in " farming " oysters, provide a bed of clean old shells on which the " setting " can take place. Spawning occurs after the first year. Oysters feed on the minute organisms or *plankton* of the sea water. If the waters in which they are grown contain sewage, there is danger of contamination with microorganisms from the human intestine — possibly with pathogenic forms. In general, today, ordinances enforced by boards of health protect the consumer from these dangers. Chemical wastes from industrial plants along shores near oyster beds are injurious. Oysters have a number of animal enemies, some of which consume the free-swimming oyster embryos. The adult oyster is eaten by starfishes and by the oyster drill, Urosalpinx, a boring marine snail.

The marketing of clams is another important sea-food industry. Millions of pearl buttons are made from clam shells.

"The pearl," says G. F. Kunz, "is the most precious, costly, richest and most beautiful of all objects of human adornment." Sometimes a boring sponge or small worm will bore through the outer layers of an oyster shell. Possibly grains of sand get in between the mantle and inner layer of shell. The oyster then deposits mother-of-pearl at this point to allay the irritation. A little mound collects and so a "blister pearl" is formed. They are used in the manufacture of jewelry. Sometimes, an irritating object gets into the connective tissue of the mantle and around this object successive layers of *nacre* are secreted until a *pearl* is formed. Various foreign objects may stimulate pearl formation. The surface of the pearl is crumpled and corrugated and the edges have tooth-like outlines. Rays of light reflected from the surface are broken up into prismatic colors, much as light is reflected from a soap bubble so that an iridescent effect is produced. Important pearl fisheries are located near Bahrein Island in the Persian Gulf, where pearls have been obtained for over twenty centuries.

At the Mikomoto Pearl Fisheries in Japan, expert workmen introduce some foreign body into three-year-old oysters, which are then placed in wire baskets. The latter, suspended from a raft, are sunk 15–20 feet below the surface of the bay and left for about five years. The oysters are then examined for pearls, which are found in about half the specimens.

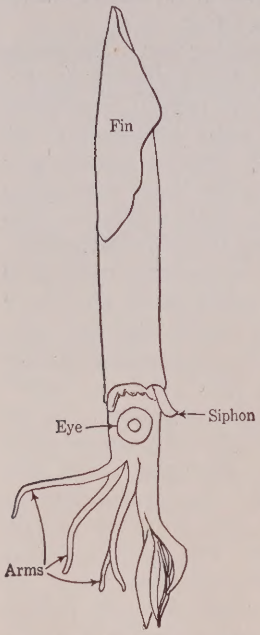

Fig. 180. — Loligo, the squid, a Cephalopod. After Drew.

Class III. Cephalopoda. These are Mollusca having a head provided with well-developed eyes. The foot is modified into tentacles which possess suckers. Examples of Cephalopods are squid (Fig. 180), Octopus and Nautilus. The squid is an active swimmer. It can capture a fish with its tentacles, hold it with the suckers and tear out pieces of flesh with its beak-like jaws. It has an ink sac, and when the ink is discharged, a black cloud of water hides the squid from its enemies. Fresh and dried squid and octopus are considered good food by many peoples. The Nautilus (Fig. 181) has a shell with spirally arranged compartments formed yearly, one after the other, to accommodate the growing animal, which occupies the outermost and latest chamber.

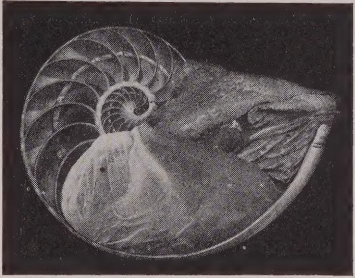

FIG. 181. — Nautilus. Shell sectioned showing location of organs. (Courtesy Am. Mus. Nat. Hist.)

Summary of Molluscan Characteristics : (*a*) Triploblastic; (*b*) Coelome restricted in adult; (*c*) body unsegmented; (*d*) no serially repeated appendages as in Arthropods; (*e*) various specialized organs, such as the foot, gills, heart, etc. (*f*) The embryological history of many forms has a larval stage known as a *trochophore.* A larva similar to this is found among marine Annelids (Fig. 173). This similarity is regarded as indicating phylogenetic relations between Annelids and Mollusks. (*g*) On the whole, adult Mollusca show little relationship with other phyla. They are a specialized and divergent group.

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CHAPTER XIII

PHYLUM—ARTHROPODA

General Characteristics. Arthropoda comprise the greatest collection of contemporary animal forms, consisting of about half a million known species. They are triploblastic Metazoa; the embryo exhibits a gastrula stage; they are bilaterally symmetrical; the digestive tract has a mouth and an anus, and has special divisions for particular functions; the coelome is limited in extent in the adult; the body is segmented and the segments bear jointed appendages. The word Arthropoda is derived from the Greek words "arthron" meaning *joint,* and "podos" meaning *foot.* Active locomotion is characteristic of many. Although all the adult body segments do not bear appendages, yet since this is mainly true of the segments of the embryo body, the opinion is maintained that the ancestors of the Arthropods, like the Annelids, possessed appendages on all the body segments. Since there appear to be fewer segments in the adult body than in the embryo, because a fusion takes place during development, it is concluded that the ancestor of the Arthropod was an annelid-like creature. This idea is strengthened by the observation that many of the internal organs resemble those of Annelids. For example, there is similarity in the central nervous systems.

Three great groups of Arthropods are discussed here, first: Crustacea, which are largely aquatic and breathe by means of gills, and have two pairs of antennae; second: Insecta, air-breathing forms with one pair of antennae; and third: Arachnida, for the most part air-breathers with no antennae.

A. CLASS — CRUSTACEA

Study of a Type — Crayfish or Lobster

The crayfish is a common fresh-water Crustacean, while the lobster, a salt-water form, is a familiar example (Fig. 182). The lobster is a larger animal than the crayfish, yet they both have the same general structure.

Body Regions. The body shows two main divisions: (*a*) *cephalothorax*, a combination of head and thorax, and (*b*) the *abdomen*. A horny or chitinous exoskeleton covers the soft inner organs. Although the head-thorax appears to be a single structure, yet there are embryological and other evidences indicating that it comprises thirteen segments, while the movable abdomen has six segments and an end piece called the *telson*. A groove marks the division between the head and thorax. The *carapace* is the hard dorsal cover of the cephalothorax and it is extended in front as the pointed *rostrum*. Side shields protect the lateral *gills*. Each segment bears a pair of *jointed appendages*. There is considerable variation in these, but an extended study of the appendages of Crustacea indicates that in spite of differences between them in the adult condition there are evidences that modifications of an original or primitive type plan have occurred during the course of evolution. Before considering this further, let us list the appendages as they occur in the crayfish.

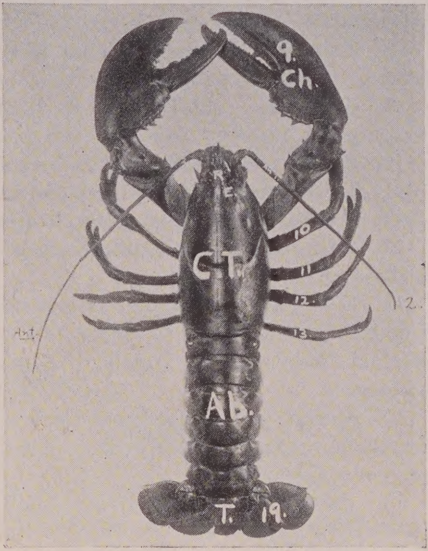


FIG. 182. — Homarus americanus — common lobster. 9. Ch. — 9th appendage (cheliped); 9-10-11-12-13. — walking legs; R. rostrum; E. eye; C. T. — cephalothorax; Ab. abdomen; T. telson; 19 — 19th appendage; Ant. 2 — Antenna. (Courtesy American Museum of Natural History.)

Appendages. 1. Antennules — most anterior possessing sense organs of touch, taste and balance.

2. Antennae — long processes, having sense organs of touch and taste.

3. Mandibles — heavy jaws for crushing food.

4. First Maxillae — very small.

5. Second Maxillae — making water currents, aerating the gills.

6. First Maxillipeds — have sense organs of touch and taste, and hold food particles.

7. Second Maxillipeds — similar in function to the preceding pair.

8. Third Maxillipeds — similar in function to the preceding pair.

9. Chelipeds — the big pincers, fighting organs; also act as walking legs, *i.e.*, first pair.

10. Second pair of walking legs, long and slender.

11. Third pair of walking legs, long and slender.

12. Fourth pair of walking legs, long and slender.

13. Fifth pair of walking legs, long and slender. They also are body cleaners.

14. First pair of swimmerets are small weak paddles in the female but stronger in the male and used to transfer sperm to seminal receptacles of female. These are first abdominal appendages.

15. Second pair of swimmerets are small weak paddles in female but in male used with first pair to transfer sperm to seminal receptacle of female.

16. Third pair of swimmerets — similar to above. These and the following fourth and fifth pairs used by female in carrying eggs until after hatching.

17. Fourth pair of swimmerets — similar to above.

18. Fifth pair of swimmerets — similar to above.

19. Sixth pair of abdominal appendages — broad flat paddles which with telson enable the animal to shoot backward quickly.

Homology. It is evident that for the most part each pair of appendages has a particular function to perform. They are not identical with each other in detail. Yet sufficient similarities are present which, considered with their embryological development and a study of appendages of various Crustacea, indicate that the primitive Crustacean (as well as other Arthropods) possessed appendages composed of similar parts on all the segments and that in the course of evolution these became modified in one way or another for particular functions. It is concluded that they were similar embryonically and that even in the adult condition they show *underlying likenesses* in structure. Basic structural resemblances indicate genetic relationships and are known as *homologies.* When they occur as resemblances between parts of the same animal they are known as *serial homologies.* The appendages of the crayfish are serially homologous. Evidences of a similar condition found in other Crustacea indicate the common ancestry of all Crustacea. Homologies are considered very reliable evidence of genetic relationships of forms that seem to be unrelated. This method of reasoning is used to a great extent in Taxonomy and in tracing evolutionary lines.

For example, the fore limbs of frogs, lizards, birds and the various Mammals exhibit a great variety of function and a certain amount of variety of structure, yet all show an essentially similar anatomical structural plan. All are homologous and this is regarded as an index of phylogenetic relationship.

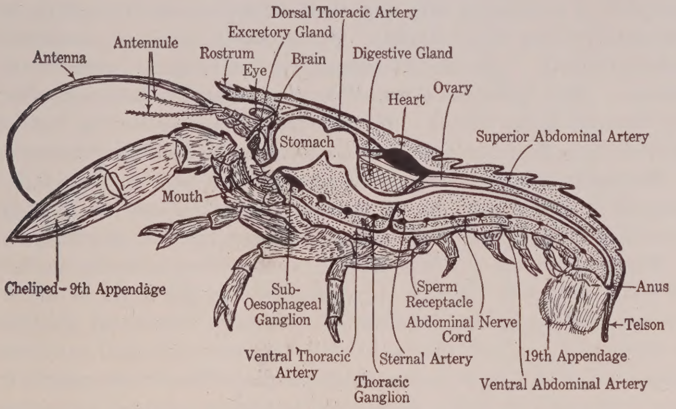

Dorsal Thoracic Artery
Excretory Gland
Antennule
Antenna
Rostrum
Brain
Eye
Digestive Gland
Ovary
Heart
Stomach
Superior Abdominal Artery
Mouth
Cheliped – 9th Appendage
Sub-Oesophageal Ganglion
Sperm Receptacle
Abdominal Nerve Cord
Anus
Telson
Ventral Thoracic Artery
Sternal Artery
19th Appendage
Thoracic Ganglion
Ventral Abdominal Artery

FIG. 183. — Anatomy of lobster. (Modified from Herrick — U. S. Bureau of Fisheries.)

Digestive Tract. Crayfish feed principally on animal matter. The maxillae and maxillipeds act as hands to hold the food so that the mandibles can separate it into small pieces to be swallowed (Fig. 183). The food passes through the oesophagus to the stomach. This is composed of an anterior gizzard-like first part, where the food is ground up between hard surfaces; then the fine food passes into the posterior stomach, where it is digested. It passes then into the intestine to be absorbed. Feces collect in the posterior region of the intestine to be ejected through the anus.

Circulatory System and Blood. The blood is a pale liquid containing ameboid white blood cells, phagocytic in function. Between the tissues are spaces called sinuses filled with blood bathing the adjacent tissues. In a dorsal sinus lies the heart, a tubular sac with openings on its side walls. A number of arteries extend from the heart to various organs. The contractions of the heart drive the blood out to various organs and into the sinuses, from which it finds its way back to the heart again — a crude sort of circulation compared with that of the Vertebrates. Plume-like gills lie in gill-chambers on the side of the thorax, beneath the lateral walls of the carapace. The second maxillae, just in front of the gill chamber, scoop the water forward, drawing a current through the gill-chamber from behind, aerating the gills. The blood contains a protein-copper compound called *haemocyanin,* which has the property of combining with oxygen absorbed through the gill membranes from the water outside. A compound called oxyhaemocyanin is formed. This blood compound serves to carry oxygen to the tissues. Here it breaks down, liberating oxygen which is absorbed by the cells of the tissues. Haemocyanin probably carries carbon dioxide back from the tissues to the gill membranes to be excreted.

Excretory System. Organs of excretion are two ' green glands,' located in the head, and they discharge their wastes through openings at the bases of the antennae (second pair of appendages).

Nervous System. The central nervous system is similar to that of the earthworm. Above the oesophagus is the brain or supraoesophageal ganglion, a fusion of primitive segmental ganglia. A nerve ring connects the brain with the suboesophageal ganglion, also a fusion of primitive segmental ganglia. Five single ganglia in the thorax and six single ganglia in the abdomen are all connected with each other and with the suboesophageal ganglion by a nerve cord ventral to the intestine.

Sense Organs. The eyes are located at the end of movable stalks. Each eye is compound, being composed of a great many (2500) little eyes or *ommatidia.* Sense organs of equilibrium or position are located in the base of each antennule. Tactile and olfactory sense organs are also believed to be present.

Muscles and Skeleton. In our bodies, the skeletal muscles are attached to the outside of the bones, while in the crayfish they are attached to the inside of the chitinous exoskeleton. In both cases the result is a mechanism of movable levers.

Reproductive System. Crayfishes are dioecious. Spermatozoa formed in the bilobed testes pass through the vasa deferentia out by a pore at the base of the fifth pair of walking legs. The testes are below the heart. Copulation usually takes place in the autumn. The male transfers sperm to the female *seminal receptacle*, between the fourth and fifth pairs of walking legs. A bilobed ovary, below the heart, and a pair of oviducts are present in the female. Each oviduct opens at the base of the third walking leg. The female produces eggs in the spring, fertilizing them as they pass by the seminal receptacle. They are attached to the swimmerets at this time and so remain until after hatching. A gentle movement of the swimmerets aerates them.

Ecdysis. As the crayfish grows it periodically sheds its " shell " to provide for the increase in size, a process known as *ecdysis*, just after which the animal is soft and defenseless.

Autotomy. Crayfishes and a number of other animals possess a remarkable property of dropping off certain of their appendages, if these are injured. The break occurs at definite joints organized for this purpose. The process is known as *autotomy*. Later a new appendage is regenerated. Autotomy and the consequent regeneration constitute processes of great defense value.

Subclasses. There are about 16,000 species of Crustacea. A few, such as land crabs and sowbugs, live on land, but most forms are marine. They feed largely on decaying animal and plant matter.

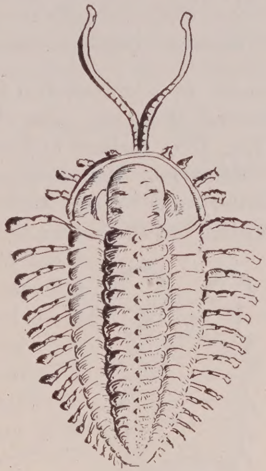


Fig. 184. — Trilobite, Triarthrus becki. (From model by Ward.)

There are two subclasses: (*a*) Entomostraca, which are very small forms and occur in great numbers in fresh and salt waters, forming no inconsiderable part of the food of the fishes of commerce. The extinct *Trilobites* (Fig. 184) belong to this class. They flourished during early Palaeozoic periods but have been extinct since the late Palaeozoic. They had a pair of antennae and many body segments all possessing appendages. (*b*) The Malacostraca are larger forms. Aristotle devised the name and he meant by it soft-shelled animals to distinguish them from hard-shelled Mollusca. The class includes lobsters, crayfishes, crabs (Fig. 185), shrimps and sowbugs (Fig. 186), land Crustaceans.

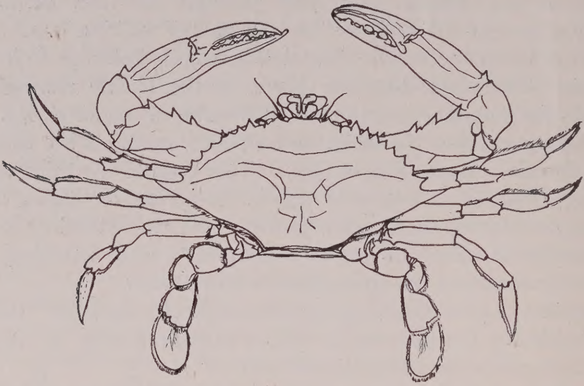


Fig. 185. — Callinectes, the Blue Crab. (U. S. Bureau of Fisheries.)

Remarks. Parasitism occurs in many forms. The parasitic forms tend to lose their appendages, segmentation and sense organs, but the organs of reproduction are more highly developed. Some Crustacea live in partnership with other animals. The hermit crab (Fig. 187) lives in the cast-off shell of some sea snail, and on the shell may also be found a colony of Hydroids (*Hydractinia*) or sea-anemones. Other crabs decorate the back of the body with seaweeds. This masking serves excellently as a defense. The Japanese spider crab is probably the largest of the Crustacea. Its small central body has long jointed legs and it may measure twenty feet from tip to tip of the first pair of legs. Lobsters, shrimp and crabs are of great economic importance. The most productive regions for lobsters have been Canada, United States, Ireland and Norway. Maine has the largest lobster fisheries in the United States. Lobsters spawn

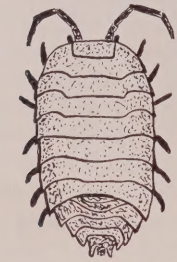


Fig. 186. — Oniscus, sowbug.

when about seven inches in length but attain sexual maturity when ten inches long. The greatest recorded length is 23.75 inches and the greatest weight thirty-four pounds.

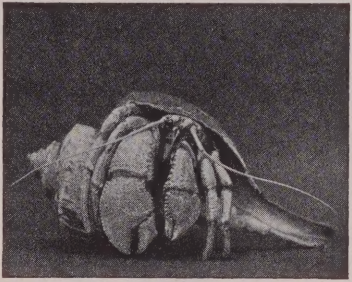


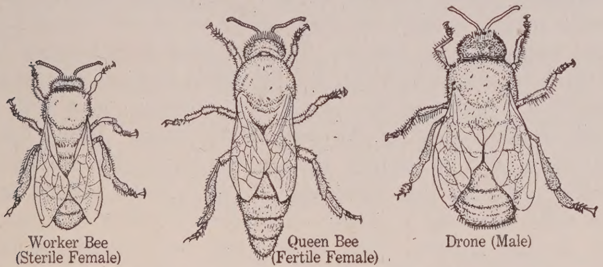
FIG. 187. — Hermit crab occupying shell of marine Gastropod. (Courtesy Amer. Mus. Nat. Hist.)

B. CLASS — INSECTA

General characteristics. These Arthropods have a segmented body, jointed legs, chitinous exoskeleton, ventral chain of ganglia joined by a nerve ring with a dorsal brain. The body is divided into three regions: head, thorax and abdomen. The head has a pair of antennae in front of the mouth and a number of pairs of mouth appendages. The thorax has three segments with a pair of legs on each. It usually has also *one pair* of wings on *each* of its *two* posterior segments. There are no appendages on the abdomen.

The Morphology and Physiology of the Honey Bee

Head. The bee is a 'hairy' insect (Fig. 188). Its body is divided into a head, thorax and abdomen. The head is rather triangular in shape, seen from in front (Fig. 189). On either side above are two large compound eyes, and on top there are three small simple eyes. From near the middle of the face originate two segmented movable antennae. Below and laterally are two strong



Worker Bee (Sterile Female)
Queen Bee (Fertile Female)
Drone (Male)

FIG. 188. — Honey bees. (From Bureau of Entomology, U. S. D. A.)

mandibles or jaws. Below the origin of the antennae and in front is a shield-like plate, the clypeus, and attached to the lower edge of this is the lip or labrum. Below the labrum, and the base of the mandibles, is the mouth. Behind the mandibles is a complicated structure called the proboscis, a very important part of it being a long flexible, hairy glossa or tongue. By means of this apparatus the bee feeds on liquids such as the nectar of flowers and on pollen.

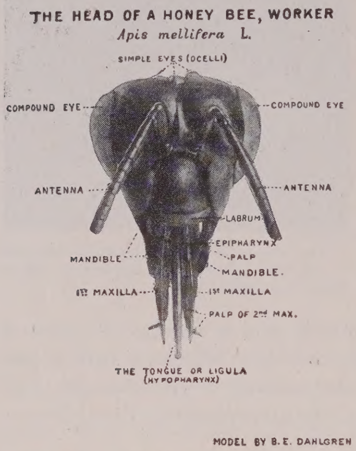

THE HEAD OF A HONEY BEE, WORKER
Apis mellifera L.
SIMPLE EYES (OCELLI)
COMPOUND EYE
COMPOUND EYE
ANTENNA
ANTENNA
LABRUM
EPIPHARYNX
PALP
MANDIBLE
MANDIBLE.
1st MAXILLA
1st MAXILLA
PALP OF 2nd MAX.
THE TONGUE OR LIGULA (HYPOPHARYNX)
MODEL BY B. E. DAHLGREN

Fig. 189. — Head parts of worker bee. Photo of model. (Courtesy of Amer. Mus. Nat. Hist.)

Thorax and Appendages. The head is movably attached to the thorax by a short, narrow neck. The thorax is short and stout. It supports two pairs of wings and three pairs of legs: prothoracic, mesothoracic and metathoracic. Each leg is a jointed structure composed of the following parts (Fig. 190), beginning with the segment next the thorax: (*a*) coxa; (*b*) trochanter; (*c*) femur; (*d*) tibia and (*e*) the five-parted tarsus terminating in two claws with an adhesive organ between them. The proximal part of the tarsus is longer, broader and larger than the others and is known as the basi-tarsus or planta. The last joint of the tarsus bears two claws by means of which the bee holds to most objects in its locomotion. Between the two claws, however, is a soft pad, usually drawn up out of the way of the claws. When the bee lights on a hard or slippery surface, the claws turn out and the adhesive organ flattens down against the smooth surface, at the same time secreting a sticky substance affording a temporary hold on the surface. The wings, legs and mouth parts are organs or tools with which the worker bee collects nectar, gathers pollen, stores it in cells, makes comb and performs all the many tasks connected with the life of a honey bee community. The legs are not only organs of locomotion but possess tools for special uses. Along the anterior edge of the tibia of the fore leg is a border of little stiff hairs, the eye brush, used for cleaning the compound eyes, which may get covered with pollen from visited flowers. The basi-tarsus or planta has long hairs forming a pollen brush, used for cleaning the front part of the body and the mouth parts. At the upper end of the basi-tarsus is a circular notch or antenna cleaner. The mesothoracic legs are larger but do not have the freedom of movement of the front legs. The basi-tarsus here is larger and broader and forms an efficient pollen brush or planta. The outer end of the tibia has a stiff spur for prying off the wax produced in the wax glands of the abdomen.

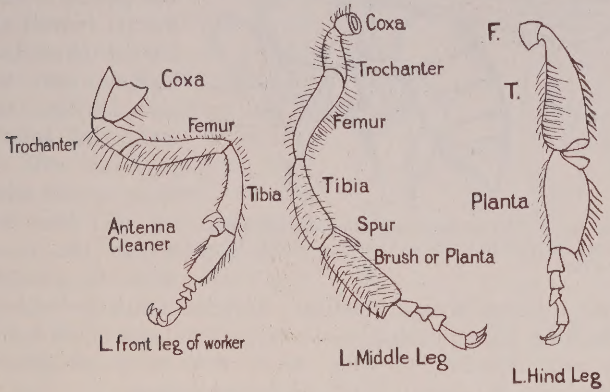


FIG. 190. — Legs of worker bee. After Casteel — U. S. Dept. Agriculture.

The metathoracic, or hind legs, are the largest and have a more diverse range of movements than the middle legs. The inner surface of the basi-tarsus with its short hairs serves as a pollen brush and also retains pollen until it can be placed in the pollen baskets, which are on the outer surface of the lower part of each tibia and consist of fringes of long hairs bending out from either edge of the tibia.

Abdomen. The abdomen of the adult bee contains six visible segments although there were twelve in the embryo, according to Nelson. The last two disappear before hatching and the eighth, ninth and tenth become modified to form structures inclosed by the seventh which appears to be the last abdominal. The first segment becomes part of the thorax. Therefore the six visible abdominal segments are the developed second, third, fourth, fifth, sixth and seventh embryonic abdominal segments. Near the posterior end of the body of the female is the ovipositor, while in the male there are appendages used in copulation. Near the tip of the abdomen, but above, are the scent glands. It is believed that bees working about flowers rich in pollen secrete a substance from these scent glands which *marks that place* for other bees who can find it from the *odor*. On the ventral surface of the abdomen are wax glands in which wax is formed as a liquid that later hardens into little plates (Fig. 191), which the bee can pry out with the spine on the middle leg and then hand up to the mouth, where the mandibles prepare it for use in comb building. Associated with the ovipositor is the sting, a complicated piece of apparatus, part of which functions as a hypodermic needle. Liquid from the poison glands is injected into the wound, causing pain and swelling.

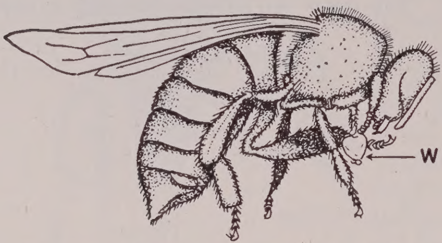


Fig. 191. — Worker bee transferring wax plate from abdomen to mouth. From Casteel — U. S. Dept. Agriculture.

The bee has a hard, chitinous exoskeleton. Segmented parts are moved by means of highly specialized muscle tissue, similar in a number of respects to the skeletal muscle of Vertebrates.

Metamerism. We have already learned that the earthworm is a segmented or metameric animal. There are many evidences of metamerism in Insects, in fact in all the Arthropoda. The head appears to be an unsegmented part of the body, and yet in the embryonic insect head there are usually six segments, most of which bear appendages. For example, the first bears the eyes; the second, the antennae; the third, appendages which early disappear and correspond to the second antennae of the crayfish; the fourth bears the mandibles. The embryonic head segments later fuse and leave no evidence, other than appendages, of the early condition of metamerism. The thorax, bearing the legs and wings, is composed of three segments, but embryonically it had four. It has already been stated that the abdomen consists of six segments derived from eleven in the embryo (or twelve if we include the first which is later part of the thorax).

Although the adult appears to be composed of only ten segments, yet we have shown that it is a modification of an embryo composed of twenty-one segments. The phenomenon of body segmentation is regarded in biology as of great theoretical interest. Many biologists regard Arthropods and Vertebrates as having been derived from segmented animals, such as the Annelids. Moreover, although the abdominal segments appear to be devoid of appendages, yet in the embryo these are present and disappear before the larva hatches from the egg.

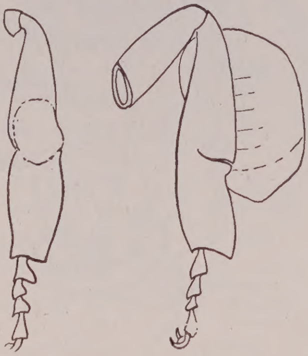


FIG. 192. — Pollen basket partly filled on leg at the left; Complete load shown in right-hand figure. From Casteel — U. S. D. A.

Pollen Collection. When bees visit flowers for pollen, they accidentally get more or less covered with it. But Casteel and Sladen have independently shown that the pollen they actually seek is scraped off and licked with the tongue and mixed with honey regurgitated from the honey stomach. The head and mouth parts get smeared with sticky pollen. It is removed by the pollen brushes of the fore legs, some of it sticking to the thorax in so doing. Now these parts are cleaned by the brushes of the middle legs. So these get filled with pollen. Then each of these in turn is taken between the brushes of both hind legs and drawn through. Let us assume that the bee has freed the planta of the left middle leg. Its pollen is now on the planta brush of the right hind leg, and then the right middle leg is cleaned next. The bee then transfers the pollen to the pollen baskets (Fig. 192).

Intestine. The alimentary canal (Fig. 193) consists of a pharynx, an oesophagus, a honey stomach or crop, a short and small proventriculus, a long and large ventriculus or true stomach and a narrow, small intestine connecting the ventriculus with the large rectum. Joined to the small intestine, at the anterior end, are about one hundred long, white, small, coiled Malpighian tubules. These are organs of excretion by which nitrogenous wastes of metabolism are removed from the blood and discharged into the intestine to be removed with the feces. The honey stomach acts as a reservoir for nectar until the bee can get back to the hive. The honey stomach also carries a supply of honey to be used in collecting pollen. The rectum is a large, thin sac forming the posterior portion of the digestive tract. Excreta and feces collect here while the bee is in the hive and retained until discharged outside. During the winter, when the bees are confined to the hive, the rectum becomes greatly distended with wastes, which are held until the first flight in spring.

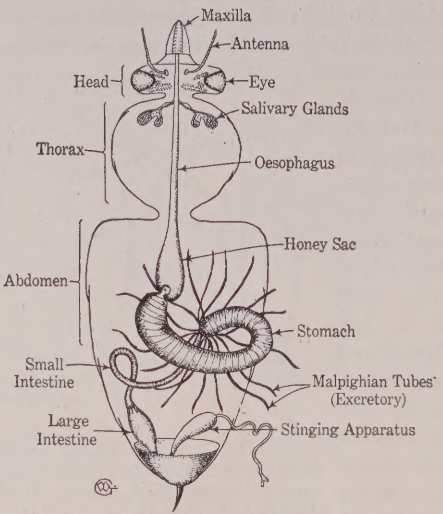


Fig. 193. — Digestive tract of bee. From Thomson (after Cheshire): *Outlines of Zoology*, D. Appleton & Co. Reprinted by permission.

Connected with the pharynx cavity are the pharyngeal glands which manufacture the brood food, — a gummy, white paste, given to the larvae in the comb cells. The queen larva is fed on this royal jelly entirely, while drone and worker larvae although given royal jelly at first have honey and pollen added on the third day and these become their main food. However, if worker larvae are fed royal jelly they become queens. It is the young workers who attend to the feeding of the larvae. Lineburg says that these young nurses pay each brood cell over 10,000 visits of feeding and inspection during the week that elapses between the time the queen lays the egg and the time the cell is capped for the pupa stage. Little is known concerning the details of digestion in the honey bee. Pollen is the primary source of protein food, while nectar and sugar given by the beekeeper are the principal carbohydrate foods. They cannot utilize *all* kinds of sugars, nor is starch digested by them. They apparently have little use for fats. Snodgrass thinks that most albuminoid absorption occurs in the small intestine.

Blood and Circulatory System. The blood is a pale, somewhat brownish fluid composed of a liquid plasma in which are ameboid wandering leucocytes functioning as scavengers of bacteria and dead cells. The blood does not contain hemoglobin. Blood fills the spaces between organs of the body cavity, and all body tissues are in a sense bathed in it. A crude sort of circulation is present (Fig. 194). A sheet-like band of muscle forms a kind of diaphragm across the upper part of the abdomen. There is another similar diaphragm ventrally. In the dorsal space or sinus formed by the dorsal diaphragm lies the long tubular heart, which extends as a fine tube through the thorax into the head. In the side walls of the larger abdominal portion of the heart are perforations communicating with the blood of the body cavity. When the ventral diaphragm pulsates, it drives the blood back and up toward the dorsal diaphragm. The contractions of this expand the sinus or space above it and so the blood is sucked into the dorsal sinus. This diaphragm pulsates, driving the blood into the heart which pumps it forward into the head, from which it flows slowly back through the thorax into the abdomen. In the process most of the tissues are bathed by moving blood and it is probable that many cells make their exchanges of food, oxygen and wastes by diffusion. It will be of interest to compare this *crude type of circulation* with that of the frog.

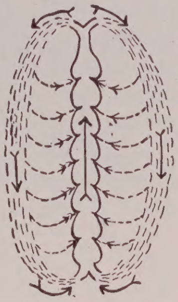


FIG. 194.—Scheme of circulation in insects. From LeConte: *Comparative Physiology and Morphology of Animals*, D. Appleton & Co. Reprinted by permission.

Respiratory System. Oxygen is delivered almost directly to the tissues through a complicated system of branching air tubes called tracheae. There are several entrances to this tracheal system from the outside. They are called spiracles, of which three pair occur on the thorax and seven on the abdomen. Associated with the tracheal tubes are large air sacs in all three parts of the body. The smallest tracheae are thin-walled tracheoles ending blindly among the tissues and permitting diffusion of oxygen and carbon dioxide. The bee exhibits respiratory movements. Inspiratory muscles expanding the abdomen cause inflow of air and expiratory muscles contracting the abdomen cause expiration of air. Some physiologists do not accept the theory that because air is thus brought so near the tissue cells, no special oxygen and CO_2 carrying compound like hemoglobin is necessary. It is known that the blood of many aquatic Invertebrates contains hemocyanin, a compound not containing iron as in hemoglobin but rather copper. Mettkowski has recently discovered the presence of copper in the "blood" of many insects also. Nevertheless, it appears as though the chief labor of delivering oxygen to tissues and removing carbon dioxide from them depends upon the tracheal system.

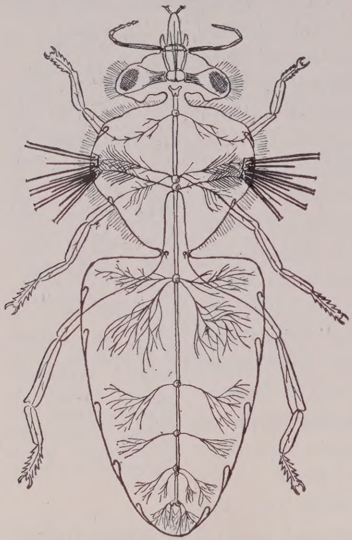


FIG. 195. — Nervous system of bee. From Thomson (after Cheshire): *Outlines of Zoology*, D. Appleton & Co., reprinted by permission.

Nervous System and Sense Organs. The nervous system (Fig. 195) resembles that of a crayfish and also that of the earthworm, though more specialized than the latter. Above the oesophagus is the large bilobed brain, a compound ganglion. This is connected by nerve cords around the oesophagus to the suboesophageal ganglion, also a compound ganglion. Behind this, in the ventral part of the body cavity, is the nerve trunk. Along its course are seven ganglia, one in the prothorax, a large compound ganglion in the thorax behind this and five smaller ganglia in the abdomen. During development, fusion of a larger number of embryonic ganglia takes place. From the ganglia, nerves go out to all parts of the body. The elements of the sensory organs, nervous system and muscles form a complexly organized adjustment system far more elaborate than is needed for a simple reflex mechanism.

The principal organs of vision are the large compound eyes. Photographs taken with the portion of an insect's eye as a lens registered as many pictures as there were facets through which vertical rays of light passed. Each little picture was slightly different from its neighbors, the facets on the right side taking more of the right side of the object, those on the left taking more of the left side of the object, etc. It is the function of the brain to *interpret* this multiple image. It is believed that insects perceive moving objects quickly; they also appear to " remember " landmarks. Bees see colors familiar to us and probably others beyond the violet end of the " human " spectrum. Observations and experiments indicate that external stimuli of various kinds arouse in the bee sensations which to us are those of vision, sound, smell, taste and feeling. Whether the insect sensation is *similar* to ours seems impossible of verification.

Although reactions of the bee to various stimuli demonstrate the above general conclusions, at the same time the exact location of many of the sense organs has not been determined. Considering the difficulties attending such investigations, the discoveries that have been made demonstrate the ingenuity of the human mind. Frisch appears to have demonstrated that the sense organ concerned in the perception of the delicate odor of flowers is located in the antennae and McIndoo has shown that sense organs stimulated by stronger odors are on other parts of the body, but Snodgrass is inclined to conclude that " there is little unanimity of opinion yet as to what function belongs to any particular set of sense organs, except the eyes."

Reproduction. The mating of a queen and a drone occurs high in the air during the so-called " nuptial flight." At this time the male copulates with the female, discharging into her vagina thousands of spermatozoa which have been formed by the testes and stored in the male seminal vesicles. After the male has discharged the sperm, secretions from the male mucous glands located near the seminal vesicles are also discharged into the vagina. These secretions coagulate preventing the loss of the sperm. In a short time the sperm pass into the spermatheca, a sac on the dorsal wall of the vagina. The queen later devotes her energies to laying eggs in the brood cells. In most of them she deposits fertilized eggs. As the eggs pass from the oviduct down the oviducts to the vagina, they pass by the orifice to the spermatheca. A sperm-pump deposits a few sperm on each egg as it passes. The fate of the fertilized eggs depends on the food furnished the larva. If entirely royal jelly, in large brood cells, queens result; if chiefly pollen and honey, in smaller brood cells, workers or infertile females develop. The queen deposits hundreds of eggs during each day of the honey season. According to Nolan, a queen observed by him kept up a daily average of 1640 eggs for twenty-six days. The sperm remain alive during the queen's entire life of four years. When the supply of eggs becomes exhausted, as may later occur, she can lay only unfertilized eggs which will develop into drones. However, Snodgrass states "So far as we know at present the working of the sperm-pump depends on the 'will' of the queen," which implies that the queen can lay unfertilized eggs although sperm still exist in the spermatheca. The development of fertilized and unfertilized eggs of the bee is later referred to in our discussion of Genetics.

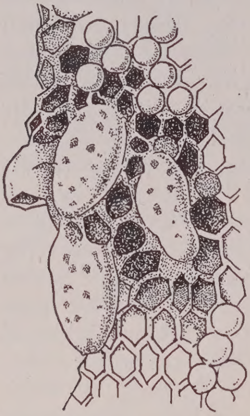


FIG. 196. — Queen cells of honey bee. From Phillips — U. S. Dept. Agriculture.

Functions of Workers. The workers, sterile females, carry on the routine work of the colony. They construct three principal types of cells. First, smaller worker cells in which workers will be raised; second, somewhat larger drone cells; and third (Fig. 196), large flask-shaped cells in which queens will be reared. In other cells honey is stored. The cells are roughly hexagonal in shape in cross-section. One group of cells is for breeding new members of the colony, and many more than these are used for storing honey to be used as food during periods when new honey cannot be made. The beekeeper takes advantage of this habit and provides *comb* both for the reserve food supply for the colony and for an extra lot of honey which he takes from the hive.

Bees drink water and carry some of it back to the hive in the honey sac, from which it is discharged into cells in which young bees are growing. The workers also get *nectar* from flowers. This is a dilute sugary solution which is swallowed and passed to the honey sac. The nectar is changed to honey in the honey sac or crop. When disgorged, it is placed in storage cells and these are not closed until it has lost part of its water. Dehydration is aided by air currents produced by the wing vibrations of many workers. This also insures a constant supply of fresh air in the hive. The workers keep the hive clean. They carry out dead bees or other insects that may have invaded the hive. The body wastes of the colony are removed. Some workers guard the entrance and prevent the admission of enemies.

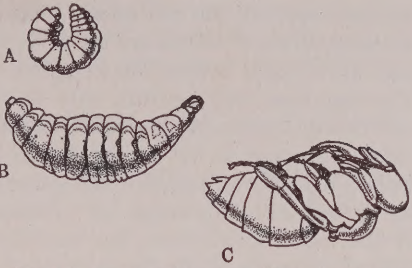


FIG. 197 *A*. — Development of bee. A. — Young larva; B. — Old larva; C. — Pupa. From Phillips — U. S. D. A.

Development. The eggs develop into larvae in the brood cells (Fig. 197 *A*). Surrounding the larva is the food placed there by the workers. When full-grown, the larval cells are capped. The larvae now form pupae. In time they leave the cells as full-fledged bees. The drones do not work, but have to find their own food. The newly formed workers at once assume duties, acting as nurses to larvae or attending to duties within the hive, but later venturing forth on food-gathering excursions. The colony gradually increases in numbers. After a drone (male) mates with a queen, the drones are disposed of.

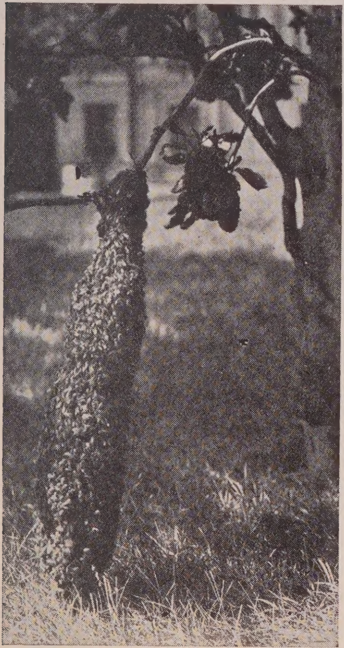


FIG. 197 *B*. — Swarm of bees. (Courtesy Amer. Mus. Nat. Hist.)

Swarming. When new young queens emerge from the queen cells, the old queen becomes restless. She attempts a combat with the new queens and endeavors to kill them. All the workers stop work and a period of unrest ensues. If the colony is in a prosperous condition, a *swarming* follows. Many of the workers prevent the old queen from attacking the new queen. Great numbers of bees leave the hive, surrounding the old queen, and fly to some hollow tree or gather on a branch (Fig. 197 *B*). The beekeeper very carefully cuts off this branch and carries the *new colony* to an empty hive which he has prepared for it. If more than one queen is left in the parent hive, the workers let the queens fight it out until but one queen is left. The young queen left in the old colony takes her " nuptial flight " with the drones. If the ruling queen dies, the workers will make large cells by tearing down the walls between three adjacent worker cells and feed the inclosed worker larva on royal food. In this way they may make several queens.

General Account of Insecta

Metamorphosis. Some insects undergo metamorphosis during their development from the fertilized egg stage, while others do not. Metamorphosis is defined as a more or less abrupt change of form during development. Two general types of metamorphosis are exhibited by insects: (*a*) Complete and (*b*) Incomplete. In *complete metamorphosis* there are four stages in the life cycle, namely, *egg, larva, pupa, adult* (Fig. 198). From the egg there hatches a *larva,* sometimes called a grub, caterpillar or maggot. This is a form greatly resembling a worm and indicating the annelid ancestry of the Arthropods. Larvae feed voraciously and increase in size quickly. They soon shed the external coat (skeleton), grow further and molt again. This occurs a number of times. Finally the larva attains its mature size. It now ceases to feed and becomes quiescent in some secluded spot. Wings and appendages of the adult are formed. Internal changes occur. The insect is now a pupa. The pupa of a butterfly is called a *chrysalis.*

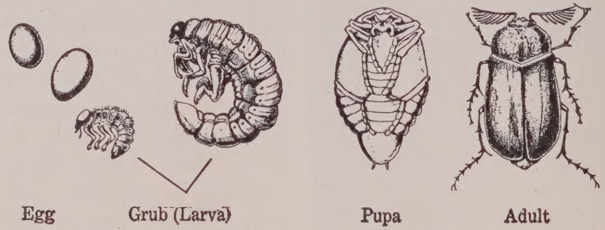
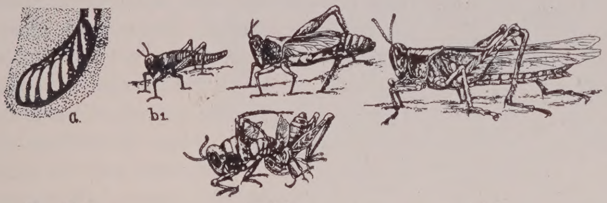


FIG. 198. — Complete metamorphosis (Beetle). Courtesy Am. Mus. Nat. Hist.

It is inclosed in a silken cocoon. It finally emerges as an adult or *imago*. The pupa often bears very little resemblance to the larva or imago. After emerging from the pupa stage the adults never increase in size.

Complete metamorphosis is exhibited by the honey bee, butterflies, moths, flies, ants and beetles.

In *incomplete metamorphosis* (Fig. 199), the larva develops from the egg. The larva grows and molting occurs as often as necessary. Wing pads appear and at later moltings these and other external structures increase in size until the mature condition is attained. There is no *pupa* or quiescent stage in this type of metamorphosis. Some forms molt three times, while others as many as twenty times in incomplete metamorphosis. The young in various stages of maturity are called *nymphs*. In many types, for example the dragon fly, the nymphs pass a longer or shorter time in water, where the eggs were laid and where the early life up to the last molting is spent. Some insects have no metamorphosis at all but are very minute replicas of the adults when they emerge from the egg. Grasshoppers, crickets, cockroaches, lice, dragon flies and may flies all exhibit incomplete metamorphosis.



Egg Nest **Moulting** **Adult**

FIG. 199. — Incomplete metamorphosis (Grasshopper). Courtesy American Museum of Natural History.

Classification. Entomologists differ as to relative importance of differentiating characters that shall determine the number of *orders* into which the class *Insecta* should be divided. Some taxonomists group in *one* order many of the *orders* of other taxonomists. Considering the fact that over a half million species are recognized, one can understand the difference of opinion and also that in this brief presentation it is not feasible to consider all orders. Insects are classified (*a*) according to the type of metamorphosis they undergo; (*b*) by the mouth parts; (*c*) according to the possession or non-possession of wings and (*d*) by the wing structure. We will now consider briefly a *few* of the well-recognized orders.

Some Common Orders

1. Coleoptera. These are beetles. The front wings are hard *elytra.* These cover the more filmy posterior wings. There is complete metamorphosis. Beetles have biting mouth parts and many are carnivorous. Some beetles devour other insects harmful to crops. Other beetles are herbivorous and so destroy leaves of valuable plants. Some bore passageways through wood of trees, causing considerable damage. Fireflies are Coleoptera. The lighting is under control of the nervous system. In the flashes of fireflies, practically no heat is generated, which is in great contrast to *our* best types of illumination. The flashes of fireflies are concerned with the process of mating. The females are more or less stationary on the ground while the males dart to and fro in the air above them. It is by means of a series of answering flashes that a male locates a female and copulation takes place. Bark beetles cause millions of dollars damage to trees every year. The cotton boll weevil (Fig. 200) is an actual menace to the future of cotton growing in the South.

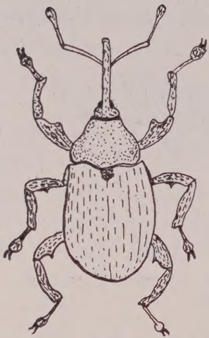


FIG. 200.—Cotton boll weevil — Anthonomis. (U. S. D. A.)

The Colorado potato beetle, *Leptinotarsa* (Fig. 201), is very destructive to potatoes, feeding voraciously on the leaves. Arsenic compounds, sprayed on the leaves of potatoes, kill the beetles, and spraying should be kept up during the growing season. The potato beetle was unknown in the eastern part of this country until the growing of potatoes reached the West where this beetle lived. It then worked its way east, following the growth of potato operations. The Japanese beetle, *Popillia japonica,* is thought to

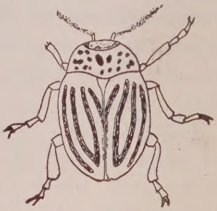


FIG. 201. — Potato beetle—Leptinotarsa. (U. S. D. A.)

have been carelessly introduced into New Jersey about 1916. Since then it has steadily increased and has spread from the center of infestation. It thrives on many kinds of fruits, flowers, crops and trees, destroying as it goes. It eats the soft tissues of leaves, as shown in the photograph (Fig. 202). If foliage is sprayed with the standard arsenate of lead, used to kill leaf-eating insects, the Japanese beetle may start feeding, but soon departs before it has received a fatal dose. The beetles appear in such enormous swarms that all known control measures are inadequate. A thoroughgoing campaign of eradication at the time of its first appearance here when the territory it occupied was small would probably have cost much less than has already been spent in attempts to destroy it and prevent its spreading. Very rigid and active quarantine measures are now in force to keep it within its present bounds.

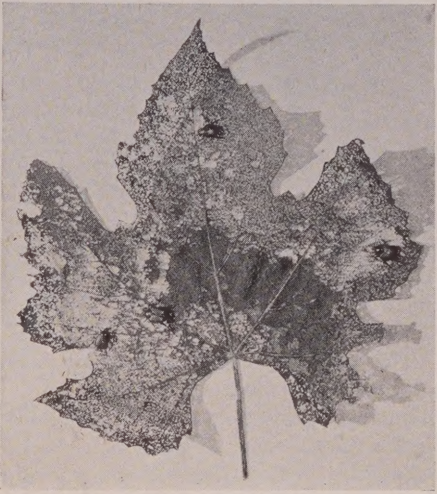


FIG. 202. — Popillia japonica destroying grapeleaf. (Courtesy Amer. Mus. Nat. Hist.)

2. Hymenoptera. The metamorphosis is complete. There are two pairs of filmy wings. Ants, bees, wasps and gallflies are common examples. Many of these insects live in colonies. There are a number of wild bees. In the case of the bumblebee, members of the colony, except fully developed females, die out in the fall. Each fertile female hibernates during the winter and in the spring starts a new colony which at first contains only infertile females. Later in the summer, older females lay eggs which develop into functional males and females. The digger wasps (Fig. 203) excavate a nest in the ground. In this nest they deposit live caterpillars stung in such a way as to be paralyzed and the female wasp lays eggs in the nest. The larvae of the wasp feed on these caterpillars. Some wasps kill their prey and tear it to pieces, feeding the young on choice bits. The solitary wasps do not live in colonies. Only males and females occur. They dig in the earth and build mud nests or bore tunnels in wood. The social wasps have a colony of males, females and sterile females, or workers. The young are not provided with stored-up food, but are cared for continuously. Some wasps build enormous nests of a paper-like substance. They scrape a small bit of wood from some exposed surface, work this up with saliva and plaster it just where needed in construction of the nest. The workers build the nest. In the late summer or early fall males and females hatch from the eggs. The males "fertilize" the females and soon after die. Workers die when cold weather comes. Fertile females alone hibernate through the winter.

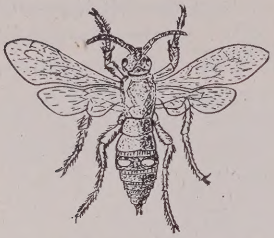


Fig. 203. — Digger wasp — Discolia. (Bur. Ento. U. S. D. A.)

The Ants (Fig. 204) form a group of Hymenoptera of which no adequate description can be given here. Among them are found architects, builders, agriculturists, masons and other types. Some have a queen, some are soldiers, some keep slaves. The workers are sterile females. Sometimes many kinds of workers are present, each type modified especially for a certain kind of work. Some ants carry pieces of leaves into the nest. These are formed into little balls on which grows a Fungus, which is food for the colony. Some ant *workers* can make a honey-like secretion with which they feed the young. Some raise grass near their colonies and harvest the seed. Other ants have established profitable relationships with plant lice or Aphids. These are carefully handled by the ants, which place them where they may obtain food. Each aphid is provided with a pair of honey tubes near the tip of the abdomen. Through these a sweet liquid is exuded when the aphids are stroked in a certain way by the antennae of the ant. The ants are very fond of this

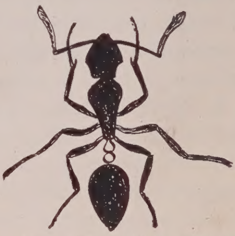


Fig. 204. — Little red ant — Monomorium. (Bur. Ento., U. S. D. A.)

food. It is stated that they carry aphids into their nests for the winter. The white, oblong bodies seen in an ant nest are pupae, being the last stage in development before the adult ant emerges.

On the whole, activities of ants are machine-like. They do not stop to consider what they do. We say their acts are instinctive. Certain observations, however, indicate that some ants at times exhibit deliberation. All the activities of the ant seem to be directed toward the welfare of the whole colony. In August, males and females from different nests of the same species undertake the nuptial flight during which mating takes place. After this the males die and the females, returning to the ground, pull off their wings and alone may start a new colony.

Most gallflies are Hymenoptera. They are small insects. The females lay their eggs under the epidermis of young leaves of oak, witch hazel, willow, some grasses and other plants. They produce an irritating substance which causes a growth to take place. This may be round like a ball and is known as a plant gall. Each type of gall insect produces a special type of gall. The larva feeds on the substance of the gall and pupates there. The mature insect eats its way out of the gall and flies away.

3. Siphonaptera. These are fleas (Fig. 205) and have no wings. They have sucking mouth parts, and metamorphosis is complete. They live among the hairs of mammals or feathers of birds. Locomotion is by leaping. One type is common to cats and dogs. The human flea has a wide distribution. The rat flea transmits the dreaded bubonic plague from rats to man.

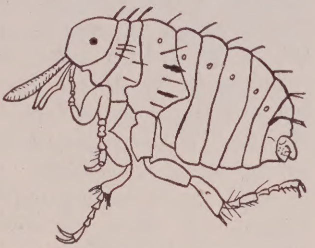


FIG. 205. — Hen flea — Sarcopysylla. (Bur. Ento., U. S. D. A.)

4. Diptera. These insects have one pair of wings on the mesothorax, sucking mouth parts and complete metamorphosis. The eggs of the mosquito (Fig. 206) are laid in water in a raft-like mass. The larvae or wrigglers live in water. At the end of the abdomen is an air tube which is projected to the air above the water. The pupa lives in water also. When completely formed, they leave the water. The larvae molt a few times, and become pupae. And these in a few days come to the surface, and the adult mosquito crawls out of the skin of the pupa.

Male mosquitoes do not suck blood, but rather the juices of plants. The females suck blood. Female *Anopheles* mosquitoes transmit malaria. *Aedes* mosquitoes transmit yellow fever. The building of the Panama Canal by Americans, after the tragic failure of the French, was made possible by first ridding the region of Anopheles and Aedes mosquitoes. This was accomplished by draining swamps and spraying a thin layer of oil over waters containing wrigglers. The latter are not able to project their breathing tubes through this oil film and hence they suffocate.

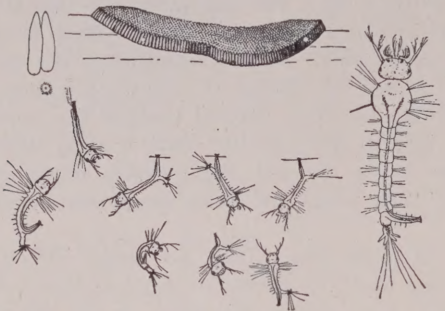


FIG. 206. — Eggs, egg mass and larvae of Culex mosquito. (Bur. Ento., U. S. D. A.)

The house fly, *Musca* (Fig. 207), is a dangerous pest. It may transmit the germs of typhoid, tuberculosis and other infectious diseases. It lays about 150 eggs in manure or garbage. The eggs become larvae or maggots. In about a day they eat voraciously, in about a week become pupae and in another week become full-fledged flies which will shortly produce another brood.

Small flies or those larger than the house fly are not the young or overgrown specimens of the house fly, but mature adults of other species. Flies do not increase in size after developing from the pupa. There are many kinds of flies and many broods are produced each summer. Plagues of house flies may be prevented by disposing of every trace of manure or animal matter on which they might breed.

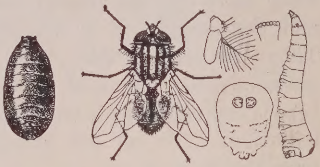


FIG. 207. — Common house fly — Musca domestica. Pupa case, adult, larva. (Bur. Ento., U. S. D. A.)

The Mediterrean Fruit Fly recently appeared in great numbers in Florida and destroyed large quantities of citrus fruit. An industry valued at many millions of dollars was threatened.

5. Orthoptera. These are the cockroaches, grasshoppers (Fig. 208), locusts, katydids, crickets and walking sticks. The cockroach (Blatella germanica) was introduced to America from Germany. Its presence indicates careless housekeeping. Walking sticks have the appearance of dried twigs, a good example of *protective resemblance.* Not only do they escape notice, but even if attacked they are of no use as food and so practically have no predatory enemies. Herrick lists six different species of grasshoppers which are injurious to crops in the United States. Linville records an observation he made in the early 1870's. A fine field of corn in the Missouri Valley was visited about noon one summer day by millions of grasshoppers. By afternoon they had eaten not only all the corn plants but every other green thing in sight. When present in such numbers their devastation is like that of a great conflagration.

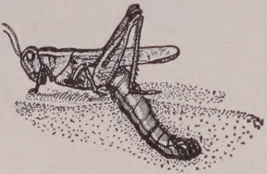


Fig. 208. — Grasshopper depositing eggs. (Webster — U. S. D. A.)

6. Hemiptera. This order contains bugs, lice and scale insects which are very destructive. They have sucking mouth parts. Three species of lice infest man: the head louse, the body louse, the crab louse. Lice have no wings but claws for clinging to hairs. The mouth parts are fitted to pierce the skin and for sucking blood. One of the body lice transmits the dreaded typhus fever. Persons free of this infected louse do not get the disease. Unclean bodies and household surroundings are favorable to lice.

Tibicina septendecim (Fig. 209), known as the Seventeen-Year Locust, lives underground as a nymph for sixteen years or so. Then it emerges from the ground, crawls up tree trunks to fresh young twigs, pierces the tender bark of these and deposits eggs. The twig beyond this point dies. In six weeks the young hatch, drop to the ground, dig their way into the earth and feed on organic matter or juices of roots, grow and molt until the seventeenth year, when they emerge as before.

Aphids, or plant lice (Fig. 210), are very destructive to crops. Some live on roots of grapevines, roots and twigs of apple trees, wheat and other cereals. Some consume leaves of such vegetable plants as the potato and turnip. During the summer the aphids are all females that lay eggs. These eggs develop into females without fertilization. This is called *parthenogenesis.* Several broods occur during the summer and an enormous number is produced.[1] In the autumn, males also appear and fertilize the eggs of the females. The last brood, thus produced, lives throughout the winter. Scale insects are extremely destructive. The San José scale (Fig. 211) came to this country from the Orient. The cottony cushion scale threatened the orange industry of California with destruction. A lady bug (beetle) (Fig. 212) from Australia was introduced to fight it. The lady bug feeds on the scale insects and thus helps to check the spread of the epidemic. It

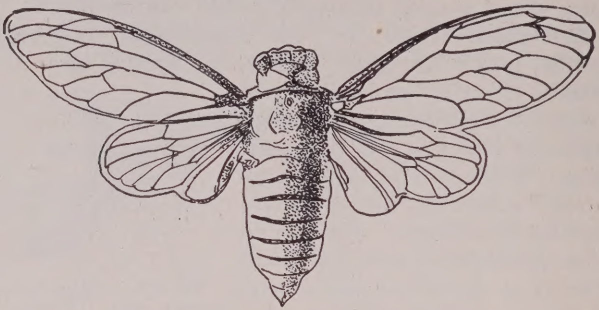


Fig. 209. — Tibicina septendecim, Seventeen-Year-Locust. (U. S. D. A.)

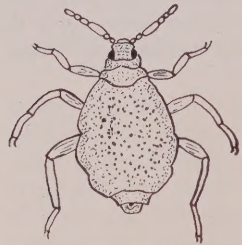


Fig. 210. — Schizoneura — Parthenogenetic female of wooly aphis of apple. (U. S. D. A.)

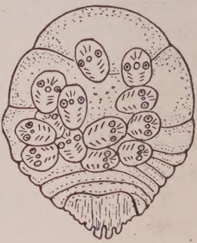


Fig. 211. — Aspidiotus — San José scale. Adult female with young. (Bur. Ento., U. S. D. A.)

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[1] S. J. Hunter estimated that a single female Toxoptera is potentially capable of producing over 200,000,000,000,000,000,000 descendants in one season of six months, beginning April 1st.

has been observed many times that when a strange form is introduced into a new country where conditions are favorable for its existence and where there are no enemies, it increases rapidly for a time until its very numbers destroy its available food supply. Enemies attack it, it loses its dominant position and finally ecological equilibrium is again restored. However, this may have brought great economic loss to man.

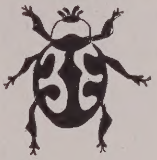

FIG. 212. — Lady bug—Novius. (Bur. Ento., U. S. D. A.)

Among the bugs should be noted the bedbug, which feeds on the blood of man and poisons him slightly each time. It multiplies rapidly in a dwelling unless vigorously attacked.

7. Lepidoptera consist of butterflies and moths. They have four wings covered with scales. The wings are often beautifully colored. There is a long sucking tube which is coiled under the head when not in use. It is used to suck the nectar from flowers. Some of the caterpillars are very destructive to plants. Butterflies have knobs on the ends of the antennae, moths do not possess these knobs. Moths fly by night, butterflies by day. When resting, butterflies often fold their wings vertically above the body. Moths when at rest have the wings spread out. The green caterpillars of the cabbage butterfly (*Pontia rapae*) (Fig. 213) feed on cabbages. The eggs are laid in among the leaves of the cabbage. This pest came from Europe about 1860 and spread all over this country from Canada. The gypsy moth (*Porthetria dispar*) (Fig. 214) came from Europe in 1868. Its caterpillars eat leaves and have been exceedingly destructive to trees in New England. It started its depredations in this country in Cambridge, Mass. The eastern states, and especially those of New England, spend huge sums of money each year in spraying trees to combat it. The adult female of the tent caterpillar (*Clisiocampa americana*) lays her eggs on wild cherry trees. The caterpillars spin a cottony, thread-like maze of fibers, the *tents*, in which they develop. From

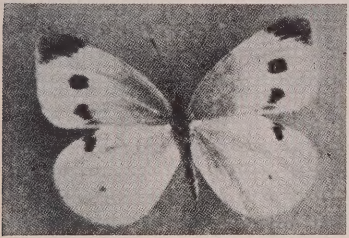

FIG. 213. — Cabbage butterfly — Pontia rapae. (Am. Mus. Nat. Hist.)

this they emerge to strip the trees almost entirely of leaves, thus causing their death.

The army worm is the caterpillar of a moth, *Cirphis unipuncta.* The caterpillars feed on wheat, oats, corn and hay crops. Once established in a region, they march on, as an army, from field to field, destroying as they go. The codling moth or apple worm lays its eggs on young apples. The larvae eat into the apples and greatly damage or destroy the apple crop. The clothes moth is small. Its caterpillars feed on furs, woolen cloth, feathers, etc. A perfectly satisfactory method of protecting clothing from its depredations remains to be found.

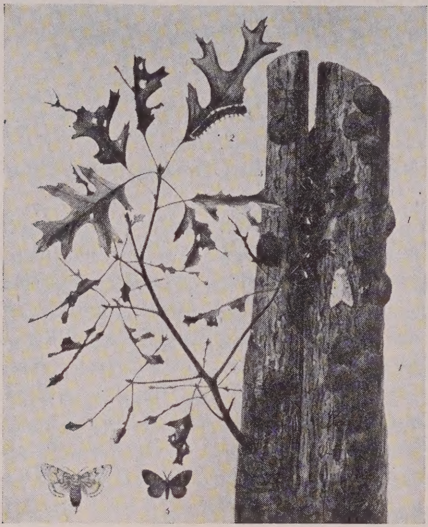

FIG. 214.—Gypsy moth—Porthetria dispar. 1.—Egg masses on trunk of oak tree; 2.—Larva; 3.—Pupa; 4.—Female; 5.—Male. (Courtesy Amer. Mus. Nat. History.)

The silkworm moth (*Bombyx mori*) is thoroughly domesticated in France and Japan. Manufacture of silk fabric is one of the great industries in America, France and Japan. Moths lay their eggs on cloth or paper and the larvae are fed on mulberry leaves. In forty days the larva spins a cocoon. This is made of one very long, slender thread. It is loosely arranged on the outside, but more compact within. The pupa is killed by heating, the loose outside thread is removed, and then the inner part of the cocoon is unwound and this is woven into thread and cloth. One of the first studies engaged in by Louis Pasteur was an investigation of a protozoan disease of the silkworm and he saved the silk industry of France.

Protective Resemblance and Mimicry. Some moths are beautiful examples of *protective resemblance* (Fig. 215). The upper surface of the wings, when the insect is at rest, blends in so perfectly with the surroundings as to escape notice. Some *edible* butterflies have the same appearance as *other species* which *nauseate* birds. This is called *mimicry* (Fig. 216). The *mimics* are thus protected because they resemble the nauseating *models.* In the same way, some *harmless* flies *mimic* bees that are avoided because of their stings.

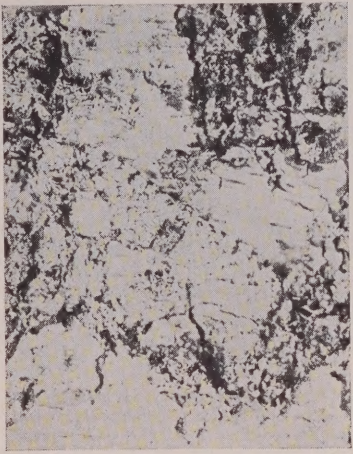

FIG. 215. — Amphidasis vetularius moth at rest on birch bark. (Protective resemblance.) (Photo by Schechter.)

CLASS C. — ARACHNIDA

Common examples of Arachnida are spiders, ticks, mites, scorpions and king crabs. They have the arthropod exoskeleton, and in many, as for example the spiders, the body is composed of a cephalo-thorax and abdomen. Spiders have six pairs of appendages attached to the cephalo-thorax. Two pairs are related to the mouth. The remaining four pairs are legs used in locomotion. The first pair of appendages are called chelicerae, the biting organs. The tip is a fang. A poison gland in the base of the chelicera secretes into a duct which opens at the tip of the fang, and by this apparatus poison is injected after the biting

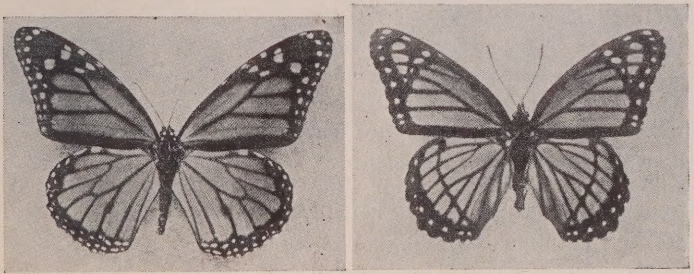

FIG. 216. — Mimicry. Left figure is the model, the Monarch butterfly (Dánais plexippus); the mimic at the right is the Viceroy (Limenitis archippus). (From photographs by Amer. Mus. Nat. Hist.)

chelicerae have pierced the skin. The poison of spiders kills their prey, which consists chiefly of insects. However, the poison of most common spiders is not virulent so far as man is concerned. On the other hand, the venom of the large Tarantulas (Fig. 217) is to be guarded against.

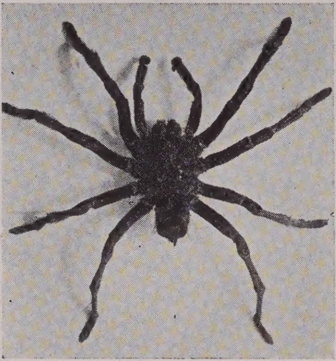

FIG. 217. — Tarantula, a large southern ground spider. This specimen had a body length of $2\frac{1}{16}$ inches and a spread of 7 inches. (Courtesy Amer. Mus. Nat. Hist.)

Scorpions (Fig. 218) are large, long, segmented Arachnids which capture insects with their pincer-like "hands" (*i.e.*, second pair of appendages). The first pair of appendages (chelicerae) are used with the "hands" in tearing the prey into pieces. At the hinder end of the body is a stinging apparatus supplied with a poison gland. This apparatus is used on larger animals, apparently when the scorpion is irritated. The effect on man depends both on the size of the scorpion and the size of the person. Small children are affected seriously.

The cattle tick, Boophilus (Fig. 219), clings to the skin of cattle with its mouth parts and sucks blood on which it subsists. The adult females drop to the ground, where they deposit their eggs in thousands. The cattle tick is frequently the host of a disease-producing Sporozoan, Piroplasma bigeminum, causing Texas fever in cattle. If the mature female is infected, her eggs will be infected. They will continue to be infected after they hatch. It is then that they crawl up on stalks of grasses and attach themselves to cattle as the latter pass by. It was demonstrated by Theobald Smith that in this way the dread Texas fever parasite

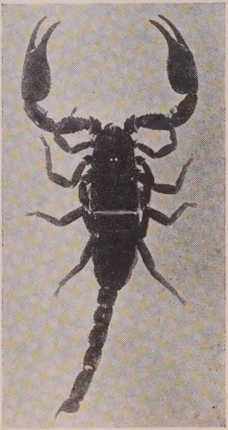

FIG. 218.—Scorpion. (Amer. Mus. Nat. Hist.)

was transmitted. Texas fever has caused a loss of millions of dollars to the cattle industry of the United States. For many years nearly three quarters of a million acres of grazing land was quarantined against cattle raising because this territory was so tick infested. After knowledge of the life history of the Sporozoan had been worked out, it was possible to undertake defense measures against it. Today in tick-infested regions, cattle are given a bath in arsenical solutions which kill any ticks that may be present.

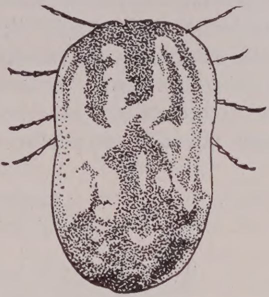

FIG. 219. — Boophilus, Texas fever cattle tick. Adult female after feeding. (U. S. D. A.)

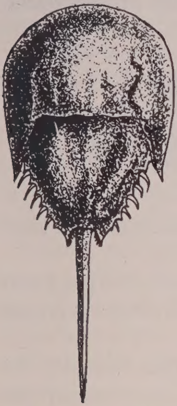

FIG. 220. — Limulus — King crab (Arachnida).

The king crab, Limulus polyphemus (Fig. 220), is found in shallow seawater on sandy bottoms along the Atlantic Coast from Maine to Central America. It is the largest living Arachnid and is unique in being a marine form. Limulus breathes by means of gills which are plate-like structures on certain appendages while there are locomotor appendages on other segments. Patten maintains that the king crab is a modern representative of the ancestors of the Vertebrates. Limulus resembles in some respects the extinct *Trilobites* which were the dominant Crustaceans of the Palaeozoic Era. It should be remembered that Limulus is an Arachnid and not a Crustacean. Centipedes (Fig. 221) belong to another class of the Arthropoda, *i.e.*, the Myriapoda.

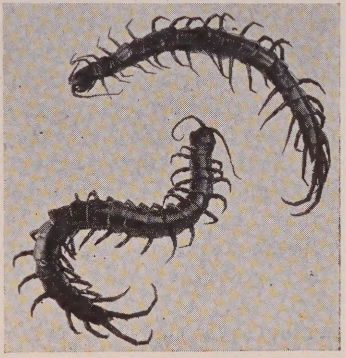

FIG. 221. — Centipedes. Class, Myriapoda. (Courtesy Am. Mus. Nat. Hist.)

Arthropod Relationships. Arthropods are related to the still more ancient Annelids because of the segmented body, with appendages borne on the segments, and because of the similarities in the nervous system. A present-day Arthropod of wide distribution exhibits many annelid affinities. It is *Peripatus* (Fig. 222), a *worm-like* form. It is considered an *Arthropod* because it has an arthropod-like heart, a limited body cavity, jointed appendages, of which one pair serve as jaws, and its organs of respiration are tracheae. On the other hand, it is *annelid-like* in having a soft skin, paired nephridia, segmented body and on the whole its organs are disposed like those of Annelids.

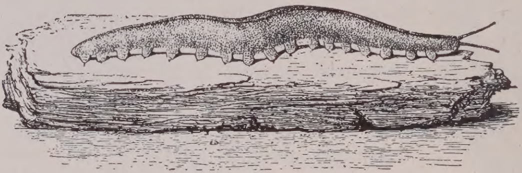

FIG. 222. — Peripatus. (After Sedgwick.) (Courtesy Amer. Mus. Nat. Hist.)

Insects in Conflict with Man. Some authorities consider the Arthropoda to be *one terminus* of *two great lines of evolution;* the *other line terminating in the Chordata.*

In a recent contribution in the *New York Times* (February, 1929), L. O. Howard, the veteran entomologist of America, emphasizes this. Man is the dominant animal of the Chordate Series, while the Insecta are undoubtedly the Arthropod leaders. The two forms have been, are now and will continue to be in deadly conflict with each other until one or the other dominates.

Insects today hold sway over large areas of country which would otherwise be suitable for human occupation. Man is dominant over insects in other territory. Insects constantly attempt to wrest from him the fruits of his labors and actually levy a great tax upon his labors.

Insects are in many ways admirably formed for biological success. The many-jointed body plan is adapted to ease of motion and locomotion. This is true of the Vertebrate as well. Many types of animals in the past have developed an external protective armor. In most cases this involved loss of active movement and has not proven to be protective in the long run of time. The insect armor, however, is many jointed and permits ease of movement as well as being protective. The chitinous exoskeleton of the insect is made of what is, in a certain sense, waste material and grows stronger with age. The bones of the Vertebrate require valuable food materials and they become brittle in the aged. The muscles of the insect are inside the exoskeleton and so protected while the muscles of the Vertebrate are outside the bones and more unprotected. The limb of the insect is said to be relatively three times as strong, architecturally, as the limb of a Vertebrate.

Insects are small and do not require much food to grow to the reproductive stage. Nor is much time required to attain this condition. They produce hosts of offspring and many breed more than once during a season. Great increase in numbers requires great increase in food supplies, it is true, but insects easily adapt themselves to a great variety of foods. They eat plants and animals; the living and the dead.

Insects can live in an environment that would be fatal to Vertebrates. Some, for example, live in the very alkaline waters of Great Salt Lake; some have been found in petroleum in California. Lutz has recently shown that the fruit fly, Drosophila, has survived subjection to rarefied atmospheres that would easily kill Vertebrates.

Human activities have favored the multiplication of certain insects. The Colorado potato beetle did not feed on potato leaves until settlements extended westward and carried potato fields into the range of the beetle; scale insects were not known in California until man developed the citrus fruit industry there; the cotton boll weevil would not be a topic of conversation in the south if cotton were not "king." The European corn-borer has *now* discovered unlimited fields for the expansion of *its empire* in the corn belt of America. Everyone who tries to grow vegetables, fruit or flowers is well aware of his insect enemies. It is constant war from springtime until autumn and many persons give up the fight.

Herrick expresses the opinion of experts when he says that the "losses caused by insects in the United States alone are estimated to aggregate more than a billion dollars annually." In 1919, it was reckoned that the loss amounted to about two billion dollars. In 1918 about thirty million pounds of arsenate of lead were used in spraying plants at a cost of over three million dollars. Out of seventy-three kinds of our most destructive insects, over half have been introduced from foreign countries. Abroad, they are not the agents of destruction that they become when brought here. A reason for this is, that here they do not have the natural enemies which held them in check in their native country. One method of combating them is to find the appropriate foreign enemy and introduce it here. Another source of loss is the change in food habits of native species. The Colorado potato beetle illustrates this. When planting operations extend to what has been formerly virgin territory, the domesticated plants are brought in contact with the native insects, which may find the introduced plant to be superior food as compared with the native wild plants on which it has been accustomed to feed. If the planting operatons are on a large scale, this new food is so much the more plentiful. Herrick lists fourteen species of native insects that have changed their food habits from wild to cultivated plants.

We have already called attention to the great monetary losses due to insect depredations. Dr. Howard states that we thus lose annually the labor of a million men in the United States alone. We spend millions of dollars annually on our army and navy for protection against enemies that might appear. But in the insects we have an actual, capable and utterly merciless foe, maintaining a constant warfare, destroying our property, stealing our food and killing our citizens. Why not invest in a real protection against an actual enemy? Why not mobilize, train and equip an adequate number of entomologic soldiers to wage aggressive warfare against them — an army of a size more commensurate with the great seriousness of the attack made upon us! This is entirely feasible and success is possible, for we have a weapon stronger than all the powers that they can muster. The weapon is human intelligence.

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CHAPTER XIV

PHYLUM — CHORDATA — PART I

General Characteristics. This phylum includes such familiar forms as fishes, frogs, lizards, snakes, birds, cats, dogs, horses and men. The embryology of Chordates exhibits blastula and gastrula stages. The diploblastic embryo becomes triploblastic and from the three germ layers — ectoderm, mesoderm and endoderm — the various specialized tissues and organs of the adult develop. A coelome is present and there are indications that the body is segmented. Chordates are bilaterally symmetrical and possess definite antero-posterior and dorso-ventral differentiation. A wide variety of animal forms is included in this phylum, but all possess three characteristics in common.

First: *Notochord.* The body at some period of life is supported by a longitudinal rod-like structure called a notochord. It extends the length of the body dorsal to the intestinal tract, which, beginning with a mouth at the front end, extends the length of the body, terminating in a posterior anus. The phylum is named after the notochord.

Second: *Gill Slits.* A portion of the digestive tract behind the jaws is called the *pharynx.* This possesses a series of vertical openings on each lateral wall of the pharynx. Membranous *gills* usually may border these openings, called *gill slits.*

Third: *Dorsal Nervous System.* The central nervous system is a hollow cylindrical tube of nerve cells and fibers, dorsal to the intestine and dorsal to the skeletal axis. In most Chordates, the anterior end is organized into a large and chief nerve center, the *brain.*

We divide the Chordata into two sub-phyla, namely, the Prevertebrata and the Vertebrata.

SUB-PHYLUM I — PREVERTEBRATA

These are small animals which have little apparent similarity to the more common and larger Vertebrates. Nevertheless, they have chordate characteristics. Three classes are noted.

Class I. Hemichorda. This class is illustrated by Balanoglossus (Fig. 223), a worm-like form, about 15 cm. long and 0.5 cm. in diameter. It lives in the sand or mud along the seashore. Three body regions are evident: (*a*) *proboscis*, (*b*) *collar*, (*c*) *trunk*. It has a long alimentary tract. The obvious claim to relationship with the Chordates is the many pairs of gill slits and gills at the anterior end of the alimentary tract. The nervous system is a diffuse network under the epidermis with thickenings along the mid-dorsal and mid-ventral line. Finally, a forward rod-like prolongation from the anterior end of the mouth, extending dorsally from the mouth into the proboscis, is said to be a notochord. Balanoglossus possesses a larval form called a *Tornaria.* Because of the resemblance of the Tornaria to certain Echinoderm larvae, some authors believe that Balanoglossus indicates a genetic relationship between Echinoderms and Chordata. But in other respects Tornaria resemble certain larvae of Annelids, and because of this it is believed by other investigators that Balanoglossus had an annelid ancestor. This seems the more plausible theory. The adult is annelid-like in a number of respects.

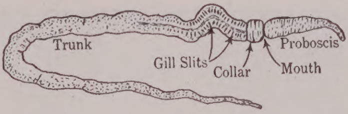


FIG. 223. — Balanoglossus.

Class II. Urochorda or Tunicata. Tunicates live in the sea. They were classified with mollusk-like animals until 1866, when Kowalsky showed their chordate characteristics. They are free-swimming, or attached sac-like forms, and are called Tunicates because the soft internal parts are protected by a tough outer *tunic.* They are sometimes called sea squirts because the animal squirts water through two tubes at the free end when irritated (Fig. 224). A common form along the Atlantic Coast is *Molgula manhattensis.* Water normally enters the animal through one of these tubes and leaves the body by the other. Oxygen and food is obtained from incoming water, and carbon dioxide, excretions, feces and reproductive cells are discharged through the other tube.

The mouth leads into a large pharynx which is perforated with a great many gill slits. Water coming into the pharynx passes out through these gill slits into the atrial chamber and thence out through the exhalent or atrial opening. At the base of the pharynx is the opening to the rest of the alimentary canal, which is bent laterally onto the pharynx, ending in the anus in the atrial cavity near the atrial opening. The simple tubular heart is located near the lower end of the pharynx. The blood is colorless. The animals are hermaphroditic, and simple sex organs lie in the loop of the intestine. Testis and ovary mature at different times. Gonaducts pass alongside the intestine and open near the anus.

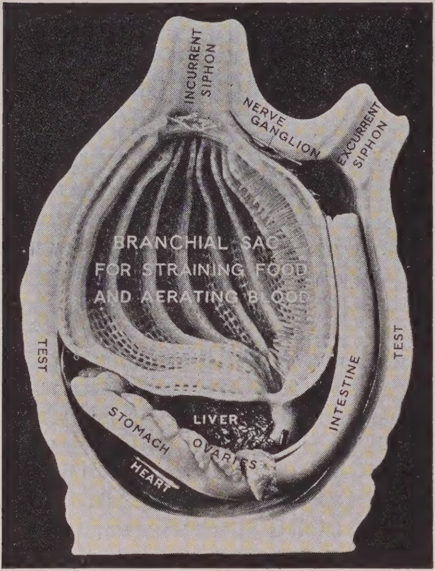


Fig. 224. — Anatomy of adult Tunicate. Photo of model. (Courtesy American Museum of Natural History.)

Tunicates in their adult condition do not appear to be Chordates. The sessile adult condition is preceded by a larval free-swimming *tadpole* form. This has an enlarged anterior end behind which is a laterally compressed tail. The tadpole has bilateral symmetry, antero-posterior differentiation and shows plainly all three chordate characteristics. First, the mouth leads into a pharynx with perforated gill slits. Second, an elongated notochord extends back to the tip of the tail. Third, above the notochord is the nerve chord.

There are some compound Tunicates, *i.e.*, many individuals are surrounded by a common tunic. In some forms the individuals have a connecting circulatory system. Tunicates also reproduce asexually by budding.

Class III. Cephalochorda. Some authors regard these as offshoots from old vertebrate ancestors, others regard them as degenerate early and very simple Vertebrates. *Amphioxus* is a common form (Fig. 225). It is bilaterally symmetrical, it has antero-posterior and dorso-ventral differentiation, a body cavity and tubular intestine. It is two inches more or less in length.

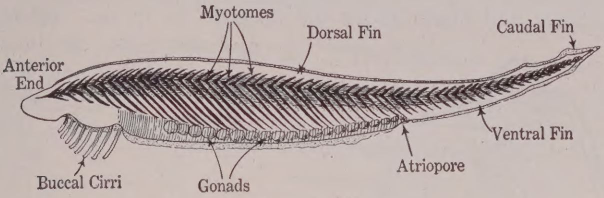

Myotomes
Dorsal Fin
Caudal Fin
Anterior End
Ventral Fin
Atriopore
Buccal Cirri
Gonads

FIG. 225. — Amphioxus.

Alive, it is whitish in color, and on the side of the body can be plainly seen the segmented " V "-shaped muscle masses or *myotomes*. Just back and under the pointed front end of the body is a circular fringe of soft appendages called *cirri*. At the base of these is the mouth (Fig. 226). The mouth leads into a large laterally compressed *pharynx* which is perforated with many *gill slits*. Water comes into the mouth, passes out through the gill slits into the *atrial chamber* (Fig. 227) and out from this through the *atriopore*, somewhat back of the middle on the ventral side and just in front of the ventral fin. Back of the pharynx is the *intestine*, which passes back from the pharynx, ending in the *anus* on the left side behind the atriopore. Near the beginning of the intestine is a forward-directed blind pouch, the *liver*, running along the side of the pharynx.

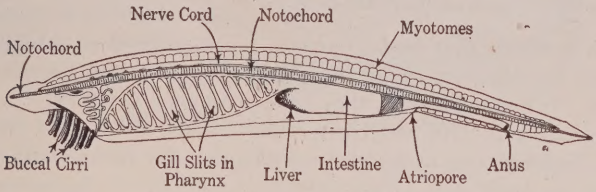

Nerve Cord
Notochord
Myotomes
Notochord
Buccal Cirri
Gill Slits in Pharynx
Liver
Intestine
Atriopore
Anus

FIG. 226. — Anatomy of Amphioxus.

Amphioxus possesses a *dorsal blood vessel*, in which the blood flows posteriorly (as in Vertebrates), and a *ventral vessel*, in which the blood flows forward. From the ventral vessel, blood flows through *afferent branchial arteries* to the gills, thus insuring oxygenation of the blood, thence from capillaries of the gills to *efferent branchial arteries*, to the *dorsal vessel*. The dorsal and ventral vessels have branches. The *notochord* is a cylindrical axis extending from the front end to the rear of the animal. There is a central nervous system, a cord-like structure, lying above the notochord, and hence above the intestine as in the Vertebrates and not under the intestine as in Annelids and Arthropods. It is slightly enlarged at the anterior end (brain). The sexes are separate. There are twenty-six pairs of gonads along the wall of the atrial cavity, from segments ten to thirty-five, lateral to the pharynx and intestine. Eggs or sperm are liberated into the atrial cavity and pass out through the atriopore into the water, where fertilization takes place.

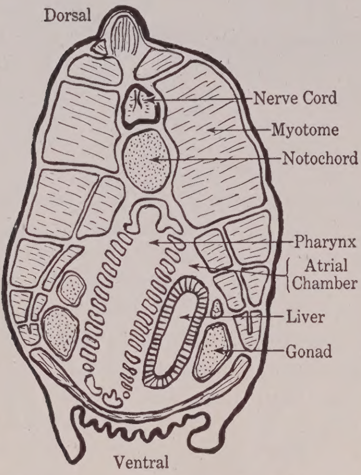


Fig. 227. — Cross-section of Amphioxus.

Amphioxus is a classic form to the biologist. The tadpole of Tunicates and the adult Amphioxus resemble each other in that both possess a much perforated pharynx, an atrial chamber, an elongated notochord and dorsal nervous system. It is thought that they have a common ancestry.

Lamarck in 1797 emphasized the marked differences between the *Vertebrates* or backboned animals and the *Invertebrates* which have no backbone. This division of the Animal Kingdom into Vertebrates and Invertebrates is not advisable because of the *number* of distinct types of body plan in the Invertebrates. But the influence of this early division of Lamarck is still felt, possibly because Man is a Vertebrate. According to the theory of evolution, the Vertebrates must have had some kind of invertebrate ancestry. Kowalsky in 1866 showed the vertebrate characteristics of Amphioxus; the resemblance of the tadpole stage of a

Tunicate to Amphioxus and later the vertebrate characteristics of Balanoglossus. Amphioxus is a simple Chordate. Tunicates, and the Hemichordate, Balanoglossus, have more invertebrate characteristics than Amphioxus. The Prevertebrates form a connecting link between Vertebrates and the Invertebrates. Some zoologists have linked Vertebrates with Annelids because of similarity in segmentation, for example.

SUB-PHYLUM II — VERTEBRATA

Characteristics. All of these forms are larger and more highly organized than the Prevertebrates. The embryos possess a notochord which is later displaced by an axial, segmented backbone composed of separate pieces called vertebrae. In the lowest groups the vertebrae are composed of cartilage and in the higher groups of bone. Vertebrates, of course, possess the other chordate characteristics, namely, dorsal nervous system and pharyngeal gill slits.

The Vertebrates may be divided into six classes: (1) *Cyclostomata*, (2) *Pisces*, (3) *Amphibia*, (4) *Reptilia*, (5) *Aves*, (6) *Mammalia.*

Class I. Cyclostomata (round mouth). An example is Petromyzon (Fig. 228). These animals resemble eels in form. They have no jaws or paired appendages. The notochord is retained even in the adult. The head and gills are supported by a cartilaginous framework; in fact the whole skeleton is cartilaginous. There is no atrial cavity. On the sides of the pharynx are external gill openings. The skin is soft and very slimy. The animals possess eyes, an olfactory sac and internal ears. The skin is provided with tactile sense organs. There is a heart behind the head on the ventral side, and there are arteries, veins and capillaries present. The brain resembles that of embryos of higher

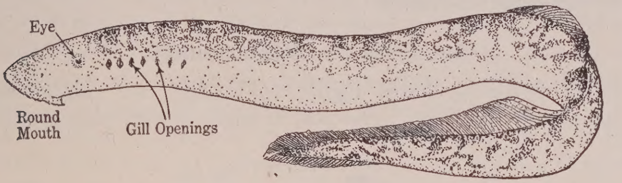


FIG. 228. — Petromyzon. (U. S. Bur. Fish.)

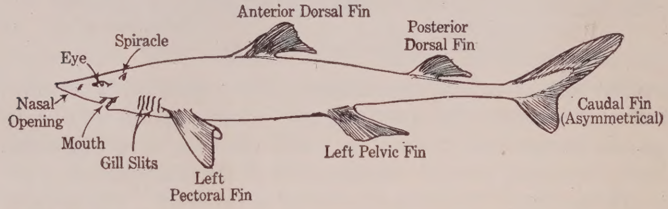
Vertebrates. There is no distinct stomach present. There is a liver but often no bile duct connecting it with the intestine. The muscular system consists of serially repeated myotomes. Kidneys are alongside the mid-line of the dorsal body cavity. An excretory duct carries urine back into a common urino-genital chamber. The sexes are separate with hermaphrodite tendencies. The sex cells break out of the gonads into the body cavity and from this through a pair of genital pores into the urino-genital sinus and thence into the water by the urino-genital aperture. Some authorities consider Cyclostomata not as primitive, but as degenerate forms.

Class II — Pisces — Fishes

Characteristics. Fishes consist of a vast number of Vertebrates adapted for life in water. In most, the organs of respiration are gills. The organs of locomotion are fins of which there are two kinds, the unpaired and the paired fins. The surface of the body is usually protected by scales. The embryonic notochord is replaced by cartilaginous vertebrae, which in a large number of cases are, in turn, replaced by bone. The skull is well developed and consists of a part which incloses the brain and another part which forms the jaws and supports for the gills. The nasal sacs do not, as a rule, open into the mouth. We will consider three sub-classes of Pisces.

Sub-Class I — Elasmobranchii

These are sharks, skates, dogfishes (Fig. 229), etc. The skeleton is entirely of cartilage. The skin is covered with placoid scales, sometimes called skin-teeth. The gill slits open to the outside and are uncovered.



Nasal Openings Invisible from Side

Fig. 229. — Squalus, the spiny dogfish. (U. S. Bur. Fish.)

External Features of the Dogfish. The study of a dogfish (*Squalus*) illustrates the general features of these animals. The body is fusiform in shape, larger in the anterior region. In front is the projecting snout. Just behind and underneath this is the mouth. At the posterior end, the body is laterally compressed and ends in the caudal fin, which is asymmetrical. The dorsal lobe is much more elongated than the ventral. This type of fin is called *heterocercal.* It is correlated with the ventral mouth. Propulsion by this type of fin would send the animals downward toward the bottom where they feed. The tail and caudal fin form the principal means of locomotion. The body is covered with *small placoid scales* (Fig. 230), which have a round, flat base from which rises a curved tooth-like spine pointing posteriorly. The body of a placoid scale is composed of dentine. Inside is a pulp cavity. The pointed tip is covered with enamel. In all these respects, the placoid scale is like a tooth; they might be called skin teeth. It is believed that the teeth of all Vertebrates are modified placoid scales, which in Elasmobranchii were found all over the external surface and inside the mouth, but which in higher animals became limited to the mouth during the course of evolution. On the lateral surfaces of the head are the *eyes.* The eye has a third lid in addition to the two usually found. This lid, the nictitating membrane, can be drawn across the eye from the inner corner. The eye of all Vertebrates is quite similar to that of the dogfish. Back of the eyes on either side are pairs of openings: (*a*) just behind each eye is a spiracle which opens into the pharynx. (*b*) Just in front of the anterior paired fins are found the five pairs of lateral gill slits.

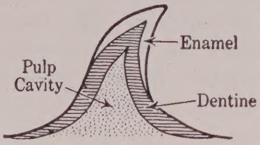


FIG. 230. — Placoid scale.

Associated with the gill slits are the membranous gills. Water for respiration comes *into* the pharynx through the mouth and probably at times through the spiracles. The water passes out from the pharynx through the gill slits, bathing the gills. In this process the blood in the capillaries of the gills takes in oxygen from the water and gives out CO_2 to the water. The nostrils are openings leading to blind sacs just in front of the mouth.

Two kinds of fins are present in fishes, paired and unpaired. The latter are median, dorsal and ventral projections. They are more primitive and they alone are found in Amphioxus and Cyclostomes. In Squalus they are the two dorsal and one caudal. Two pairs of lateral fins (limbs) are present. The forward pair are called *pectoral* fins, while the posterior are the *pelvic* fins. Each pair is attached to a cartilaginous ring inside the body; the pectorals being attached to the *pectoral girdle* and the pelvics to the *pelvic girdle.* The paired fins are strengthened by small bars of cartilage. The theory has been advanced that these cartilage bars are the fore-runners of the bones of the higher vertebrate limbs. Between the bases of the pelvic fins is the *cloaca,* terminating in the *anus,* the slit-like external opening of the alimentary tract.

Muscles. Underneath the skin are the segmentally repeated muscles or *myotomes,* showing similarities to those of Amphioxus and Cyclostomes, and recalling the segments of the earthworm. In the region of the paired fins the body muscles are modified to move the fins.

Skeleton. The skeleton is cartilaginous. It is divided into the *axial* and the *appendicular* portions. The axial skeleton consists of the skull and the segmented vertebral column. The embryonic notochord still persists in spaces between the centra of the hourglass-shaped vertebrae. The skull consists of a cartilaginous box-like *cranium* inclosing the brain, and the *visceral skeleton.* The latter consists of a series of cartilaginous bars forming the jaws and supporting the gills. The embryonic skeleton of higher animals is in many general respects similar to that of the adult dogfish. The bony skeleton of higher Vertebrates is preceded by a cartilaginous skeleton. The *appendicular skeleton* is the cartilaginous framework of the girdles and paired fins described above.

Intestine. The digestive tract (Fig. 231) is a little longer than the body. Behind the jaws with their rows of teeth is a large space, the *pharynx,* from which open out the *spiracles* and *gill slits.* The pharynx leads into the short, wide *oesophagus* which opens into the " V "-shaped *stomach.* At the intestinal end of the stomach is a valve (*pyloric sphincter*) which controls the discharge of food from stomach to intestine. The *small intestine* is very short. Behind it is the *large intestine,* inside of which is a central axis from which a spiral membranous shelf runs to the outer wall. This is called a *spiral valve.* Thus the internal surface of the intestine is increased. Attached to the hinder end of the intestine is the *rectal gland.* The intestine opens into the *cloaca* at the posterior end of which is the cloacal aperture, or *anus.*

The *liver* consists of two large lobes. Ducts from these lobes carry the liver secretions into the common *bile duct* and so into the intestine. A side branch leads to the *gall bladder,* in which bile is stored. The gall bladder is imbedded in the liver. Along the left bend of the stomach is the dark red *spleen.* Farther on and extending between the pyloric end of the stomach and the intestine is the whitish *pancreas.*

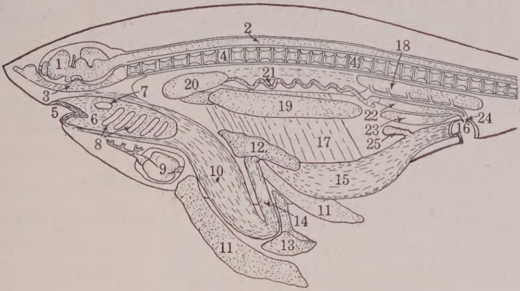


FIG. 231. — Anatomy of dogfish. 1, Brain; 2, Spinal cord; 3, Floor of skull; 4, Spinal column; 5, Mouth; 6, Pharynx; 7, Spiracle; 8, Gill slits; 9, Heart; 10, Stomach; 11, Liver; 12, Pancreas; 13, Spleen; 14, Small intestine; 15, Large intestine; 16, Cloaca; 17, Mesentery; 18, Kidney; 19, Testis; 20, Epididymis; 21, Vas deferens; 22, Seminal vesicle; 23, Sperm sac; 24, Urino-genital papilla; 25, Rectal gland.

Urino-genital Organs. Lying against the dorsal wall of the body cavity are the gonads. These are elongated white *testes* in the male. In the mature female the developing eggs, some quite large, may be seen in the *ovary.* The *oviducts* are long tubes lying against the dorsal wall of the body cavity. They join anteriorly under the intestine and there is a common opening here through which the eggs enter. When ripe, they are discharged from the ovary into the body cavity and from this pass into the opening common to both oviducts. Fertilization takes place in the oviduct. Here the eggs develop and *young dogfish are born, i.e.,* they pass down into the cloaca and out into the water, where they are capable of leading an independent life. The kidneys are narrow elongated organs which lie on each side of the dorsal midline covered with peritoneum, the membrane which lines the body cavity. Urine passes from the kidneys through ducts called ureters to the cloaca.

The testes of the male are connected with the cloaca by *sperm ducts*. Connected with the pelvic fins of the male dogfish are a pair of processes called *claspers* used in mating. Copulation takes place, *i.e.*, fertilization is internal. The cloaca receives undigested matter from the intestine, excretion from the kidneys and reproductive cells from the gonads (*i.e.*, ovaries or testes).

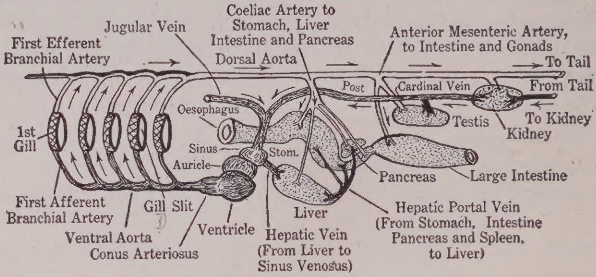

Coeliac Artery to Stomach, Liver Intestine and Pancreas
Jugular Vein
First Efferent Branchial Artery
Anterior Mesenteric Artery, to Intestine and Gonads
Dorsal Aorta
To Tail
Post
Cardinal Vein
From Tail
Oesophagus
Testis
To Kidney
Kidney
1st Gill
Sinus
Stom.
Auricle
Pancreas
Large Intestine
First Afferent Branchial Artery
Gill Slit
Liver
Hepatic Portal Vein (From Stomach, Intestine Pancreas and Spleen, to Liver)
Ventricle
Ventral Aorta
Conus Arteriosus
Hepatic Vein (From Liver to Sinus Venosus)

FIG. 232. — Plan of circulation in dogfish.

Circulatory Apparatus. The *heart* is ventral to the pharynx. It is located in the pericardial cavity just above the ventral portion of the pectoral girdle. A canal connects the pericardial chamber with the abdominal cavity. The heart consists of a single *auricle* and *ventricle*. The course of circulation is briefly as follows (Fig. 232): The venous blood, collected from all over the body by the veins, is emptied into a large, thin-walled sac, the *sinus venosus*, posterior and dorsal to the auricle and thence into the auricle. This contracts and pumps the blood into the more muscular ventricle. When this contracts, a valve closes between auricle and ventricle. From the ventricle the blood passes forward through the *conus arteriosus* and thence into the *ventral* aorta under the floor of the mouth. From this ventral aorta the blood flows through *afferent branchial arteries* to the capillaries of the gills. Here the blood is oxygenated and also gives out CO_2 to the water. From the gill capillaries the blood passes up through *efferent*

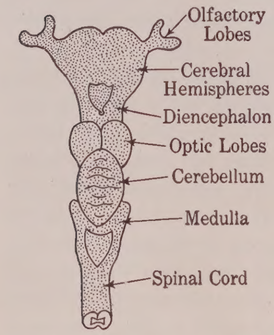

Olfactory Lobes
Cerebral Hemispheres
Diencephalon
Optic Lobes
Cerebellum
Medulla
Spinal Cord

FIG. 233. — Brain of dogfish, dorsal view.

branchial arteries to the *dorsal aorta* and from this is distributed to all parts of the body. The afferent and efferent branchial arteries are called *aortic arches* because they form arches around the pharynx and form a dorsal aorta.

Nervous System. The dogfish has a well-developed nervous system. There is a brain, spinal cord, cranial or brain nerves and spinal nerves. The brain consists of (Fig. 233) two large olfactory lobes, a pair of cerebral hemispheres, a small diencephalon, a pair of optic lobes, a cerebellum, and a medulla, similar in fundamental respects to the brain of higher Vertebrates.

General Account of Elasmobranchs. They have a cartilaginous skeleton with traces of notochord still persisting, placoid scales, spiral valve in the intestine, claspers in the male. They have a heterocercal tail and ventral mouth. The heart contains venous blood. Fertilization is internal. Some forms, as the skate, lay eggs (*oviparous*) protected by horny egg cases. Others, as the dogfish, bring forth living young (*viviparous*). The eggs generally are large and well stocked with food (yolk). In *Mustelus* there is a *placenta-like* connection between the yolk sac of the embryo and the uterus of the mother. Some zoologists call such forms ovi-viviparous since there is no true placenta present (see page 276).

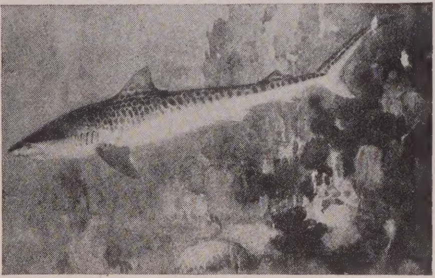


FIG. 234. — Galeocerdo — Tiger shark. From painting by Charles Knight. (Courtesy Amer. Mus. Nat. Hist.)

The word " shark " (Fig. 234) is a general name which includes forms like the dogfish, which are sometimes called dogfish sharks. True sharks have large, triangular-shaped teeth with notched edges adapted for grasping and cutting. Dogfish and skates have rows of small teeth. Sharks live more in the open sea than skates and rays, which are shore-dwelling forms.

Skates (Fig. 235) and rays dwell on the sea bottom and are flattened dorso-ventrally, with greatly developed pectoral fins. The food of these animals consists of fishes, squid, crabs, lobsters. Dogfish and sharks cause great damage to the nets of fishermen.

It is believed that they are responsible for the decrease in numbers of lobsters. Skates, dogfish, and sharks are used to a certain extent as food. The livers of all the Elasmobranchs are valuable as a source of oil, and formerly the outer layer of skin containing the placoid scales was used as an abrasive. Watch cases and sword handles were covered with this *shagreen.* Methods have been discovered of separating the scale-bearing part of the skin from that underneath and the deeper layers tan into good leather. The only obstacle to the development of this industry is the difficulty in securing skins.

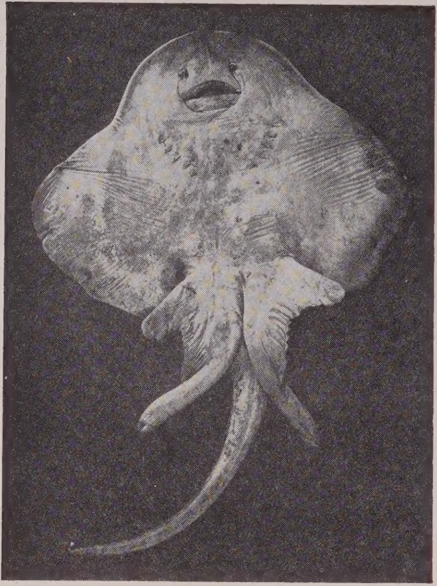


Fig. 235. — Ventral view of male skate. (Amer. Mus. Nat. Hist.)

Sub-Class II — Teleostomi

These are the common fish such as trout, perch, bass, cod (Fig. 236), mackerel, salmon, *i.e.*, types comprising the "harvest" of the world's fisheries and many others. They have many of the characteristics of the Elasmobranchs — in fact, the latter are regarded as ancestral to the Teleostomi, which, in turn, are regarded as a specialized *offshoot* from the line of evolution leading from Elasmobranchs to Amphibia.

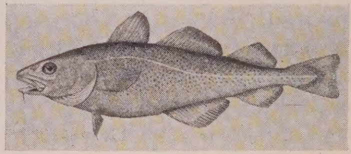


Fig. 236. — Gadus, the cod fish. (U. S. B. F.)

General Characteristics. Let us consider some of the peculiarities of the Teleostomi.

(1) Skeleton. The cartilaginous skeleton of the embryo is replaced by bone.

(2) The mouth, as a rule, is terminal, and not underneath as in Elasmobranchs.

(3) The tail is symmetrical, that is, the dorsal and ventral lobes are equal. The type of tail indicates a straightforward mode of swimming and the terminal mouth is adapted to feeding during swimming.

(4) Though some, such as eels, have a slimy, naked skin, yet most *teleosts* have flat scales covered with a thin integument.

(5) The gills are covered with a flap called the operculum.

(6) The fins are generally supported by jointed fin rays.

(7) Most Teleosts have a membranous sac in the body cavity along the dorsal mid-line. This is called a *swim bladder*. It is connected with the gut in some forms and not so connected in others. It is, in some species, filled with gas by the secretion of the cells which line it. The contents of the bladder can also be absorbed. It is a hydrostatic organ, since the buoyancy of the fish is increased when the swim bladder is inflated; when deflated, the opposite condition is attained.

(8) The eggs are smaller and greater in number than those of Elasmobranchs. There is great variation in the number of eggs produced. For example, the marine cat-fish, *Felichthys*, produces as few as fifty eggs at a time, while the cod may spawn over nine million. *Most* of the cod eggs do not mature. In most cases both eggs and sperm are discharged into the water, where fertilization takes place.

(9) Associated with the act of spawning are the remarkable migrations of such forms as the salmon and the eel. The eel which spends most of its life in fresh waters will travel great distances to very deep waters of the ocean to breed and from these ocean depths the young eels retrace the watery highways of their parents. The salmon overcomes great obstacles, and to spawn may travel over a thousand miles to the headwaters of the lake or stream

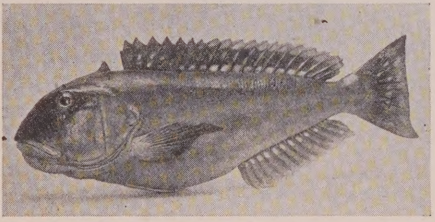


FIG. 237.— Lopholatilus — Tile fish. (U. S. B. F.)

in which it was born some years before. After spawning the parents die. Many unexplained phenomena connected with the migration or distribution of fishes occur from time to time. The *tile-fish* (Fig. 237), an important large deep-sea food fish, was abundant off the coast of New England for many years, then absolutely disappeared, only to reappear several years later.

The Fisheries. It is estimated that the annual value of fishery products amounts to about a billion dollars yearly. The most important food fishes are herring, salmon, cod, haddock, hake, pollock, mackerel and tuna. Fish constitute the main source of protein food of many maritime peoples. Fishery products are preserved by refrigeration and cold storage, by salting, by smoking, drying and canning. Among the by-products are oils used in making paints and soaps. The medicinal properties of cod-liver oil are well known. (See Vitamins, Chapter XXIII.) Glue can be extracted from fish wastes, and then the residue can be made into fish meal, a food for poultry, or as part of fertilizer for the soil.

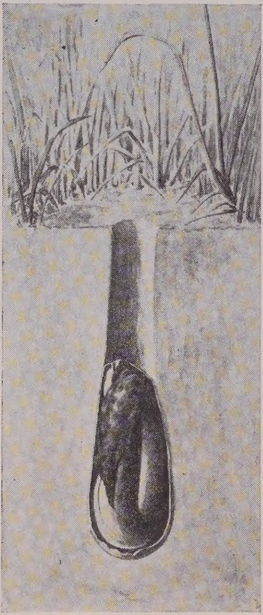


FIG. 238. — Protopterus, African Lung Fish in mud nest. (Courtesy Amer. Mus. Nat. Hist.)

Sub-Class III. Dipnoi

There is also another small though distinct group of fishes called *Dipnoi* or Lung Fishes (two kinds of breathing apparatus). They are large, fresh-water, mud-dwelling forms. They breathe by means of gills, while under certain conditions the modified swim bladder acts as a lung. The *external nares communicate with the mouth cavity*. There is a *partly divided auricle, i.e.*, it has a *right* and *left* portion. *Neoceratodus* is found in Australia; *Protopterus*, in Africa; and *Lepidosiren*, in South America. They are highly specialized and are *not* to be regarded as the ancestors of the Amphibia. They can live out of water to a certain extent and at that time the air-bladder functions as a lung. According to one theory the fin skeleton of Neoceratodus is the forerunner of the limb skeleton of Amphibia and higher Vertebrates.

During the dry season Protopterus (Fig. 238) burrows into the mud, forming a sort of slimy case in which it remains dormant, *i.e.*, *aestivates*. The specialized swim bladder functions as an organ of respiration. The energy for living functions comes from the metabolism of food stored in its tissues.

Evolutionary Significance of Cyclostomata and Pisces. The Cylostomes are regarded by many zoologists as degenerate and specialized survivors of some primitive ancient form. The Teleostomi are certainly specialized forms and this is true of the Dipnoi also. Each has developed along its own particular line and neither can be considered ancestral to the Amphibia. It is the Elasmobranchs which have remained the most primitive of the fish-like forms, and so in our geneological tree of organisms we have placed ' ancient sharks ' *on* the line of evolution leading to the Amphibia.

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CHAPTER XV

PHYLUM CHORDATA — PART II

SUB-PHYLUM VERTEBRATA. CLASS III — AMPHIBIA

General Characteristics. The Amphibia are Vertebrates which occupy a land habitat, though still remaining for the most part near or in water. All are averse to salt water. Some breathe entirely by means of gills, while others breathe by means of gills during the tadpole stage, but after metamorphosis by means of lungs. The nostrils open into the mouth, and air for the lungs is drawn in through these passages. The heart has one ventricle and two auricles. The left auricle receives oxygenated blood from the lungs while the right auricle receives blood returned from the rest of the body. Paired limbs are present. Their structure is typical for all higher Vertebrates. The differences between paired fins of fishes and limbs of higher Vertebrates are greater than the resemblances. Huxley first noted the great similarities between Fishes and Amphibia and united the two groups, giving them the name *Ichthyopsida*. There are also many differences.

Differences between Fishes and Amphibia

Fishes	*Amphibia*
1. Gills present throughout life.	1. Gills may be lacking in adults.
2. Swim bladder acts as a lung only in Dipnoi and a few other types.	2. Lungs present in many.
3. Paired appendages are fins.	3. Paired appendages are legs with digits.
4. Heart has two chambers.	4. Heart has three chambers.
5. Usually scales or bony plates.	5. Skin slimy. Fossil forms and a few modern forms with bony plates on surface of body.

Fishes	*Amphibia*
6. Nostrils do not open into mouth except in Dipnoi.	6. Nasal passages from external nares to mouth cavity.

The most commonly known forms of Amphibia are frogs and toads, of which there are many kinds. A general description of a frog, of the genus Rana, follows.

Study of a Type: The Frog. Its Anatomy and Physiology

External Features. The body is divided into the head and trunk, there being no neck. The head is about as broad as long, triangular in shape and somewhat flattened vertically. The wide gaping mouth is in front. At the tip of the snout are the two small external nostrils. The eyes protrude somewhat from the upper lateral region of the head. Behind the eyes are the circular ear drums or tympanic membranes on a level with the surface of the head. The front limbs are short and weak and are used merely to support the front end of the body. The hind limbs are long and powerful. They form the main organs of locomotion. There is no tail. The skin is smooth and loose. In the skin are many glands, secretions of which keep the skin moist. Pigment cells are found in the skin. To a certain extent the frog can " change its spots," due to diffusion or concentration of the pigment in these cells. This action is under the influence of the nervous system.

Muscles. Underneath the skin are the *skeletal muscles*, that is, those associated with the skeleton in body movements. These muscles are supplied with nerves and in response to motor nerve impulses give quick contractions. Muscles are attached to bones by means of tendons which are white, inelastic cords of connective tissue. For moving parts of a limb, muscles occur in pairs, antagonistic in action. That is, there are *flexors* and *extensors*, *adductors* and *abductors*, *depressors* and *levators*. When one member of a combination contracts, its mate relaxes, and vice versa. Thus orderly movement is possible. This would not be the case if all relaxed or all contracted at the same time. Team work is essential. The frog has many muscles. Careful dissection of the muscles of the hind limb would reveal at least eighteen principal ones. Under the mouth, forming part of its floor, is the *mylo-hyoid.* Its contractions raise the floor of the mouth, making the mouth cavity smaller and thus forcing air into the lungs. The *pectoralis* muscles are a pair of large fan-shaped muscles extending from the mid-line of the ventral surface of the pectoral girdle outwards to be inserted into the upper part of the arm on either side. Their contraction moves the front legs. The *rectus abdominis* is a flat muscle on the middle ventral side. On either side of it, forming the ventral and lateral sides of the trunk, is the *obliquus externis.* The *gastrocnemius* is the muscle of the calf of the hind leg. It has its origin at the lower end of the femur and is attached by a broad tendon to the foot. This is the *tendon of Achilles.*

The frog leaps on land. The front of the body is held off the ground by the fore legs, the trunk and head form an angle with the earth. The hind legs are folded alongside the body. The powerful muscles contract, the hind legs suddenly straighten out, and the body is hurled through the air. In the water, frogs oftentimes float beneath the surface with just the tip of the snout exposed and the hind legs hanging down. If surprised, they double up or fold the hind legs; the forelegs depress the front end of the body, the hind legs suddenly straighten out and the animals disappear into the depths below. The frog propels itself in the water by the powerful strokes of the hind legs. The web between the toes and the spreading out of the toes as the legs kick back in swimming, help to propel it through the water rapidly.

Skeleton. Most of the skeleton of the frog is bone (Fig. 239). The *axial skeleton* consists of the skull and vertebral column. The *appendicular skeleton* consists of the pectoral and pelvic girdles and the bones of the limbs. The *skull* is somewhat flattened and has a number of open spaces (fenestrae) in it. It is composed of a number of bones. The *vertebral column* consists of nine vertebrae and a long posterior bone called the *urostyle.* The *pectoral girdle* and *sternum* form an incomplete arch around the front part of the body. The girdle does not form a bony union with the backbone but is joined to it by tendons, ligaments and muscles. The *pelvic girdle* consists of three pairs of bones. One pair (the *ilia*) have long extensions. The anterior ends of these are immovably fixed to the outer ends of the transverse processes of the ninth vertebra. The hinder end of the urostyle rests in a depression above the pelvic arch at the junction of its parts. This arrangement makes a strong apparatus, well adapted to withstand the strains of leaping. The fore limb skeleton consists of a *humerus,* the *proximal* end of which articulates by a movable junction at a certain point on the shoulder girdle. Distal to the humerus is the *radio-ulna* which is a fusion of two bones — the radius and ulna. Distal to these are the *carpal* or wrist bones and beyond these are the hand bones or *metacarpals,* to which are attached the digits, and of these the second, third, fourth and fifth are present, the first (thumb) or *pollux* being *vestigial.* The bones of the digits are called phalanges.

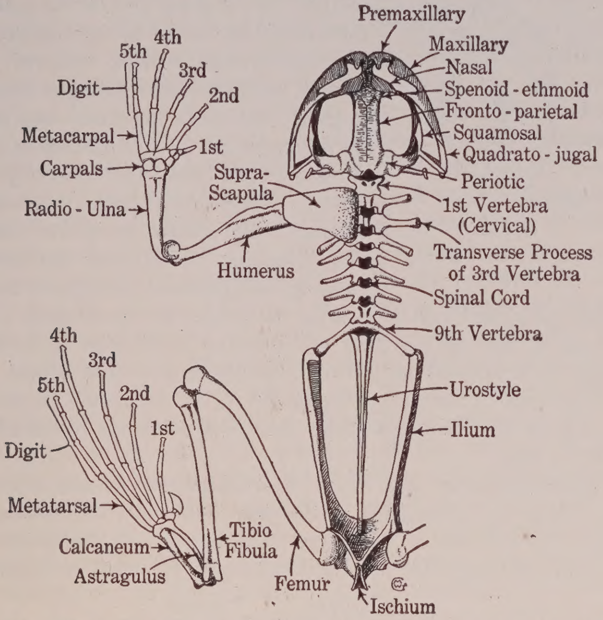

Premaxillary
Maxillary
Nasal
Spenoid - ethmoid
Fronto - parietal
Squamosal
Quadrato - jugal
Periotic
1st Vertebra (Cervical)
Transverse Process of 3rd Vertebra
Spinal Cord
9th Vertebra
Urostyle
Ilium
Ischium
Femur
Tibio Fibula
Astragulus
Calcaneum
Metatarsal
Digit
1st
2nd
3rd
4th
5th
Humerus
Supra-Scapula
Radio - Ulna
Carpals
Metacarpal
Digit
1st
2nd
3rd
4th
5th

FIG. 239. — Skeleton of frog. From Thomson, *Outlines of Zoology.* D. Appleton & Co. Reprinted by permission.

The hind limbs begin with the thigh or *femur* bone, the proximal end of which forms a *ball-and-socket joint* with the socket or *acetabulum* on the side of the pelvic girdle. Distal to the femur is the *tibio-fibula,* which is a fusion of the tibia and fibula bones. At the outer end of this bone are two long, slender ankle bones (*tarsals*), (*a*) the astragalus and (*b*) calcaneum. At the distal end of these are three more *small* tarsal bones. Then come the five foot bones or *metatarsals,* at the end of each of which is a *digit* composed of phalanges.

Mouth. There is a large mouth cavity (Fig. 240). The flat broad *tongue* lies on the floor of the mouth, is attached at the front end and is free underneath and behind. It is slimy and can be quickly extended, the forked tip curling around and capturing moving insects and worms, which are then brought into the mouth. The *teeth* are small and occur on the upper jaw. Two patches of teeth (*vomerine*) are found on the roof of the mouth. They merely prevent the escape of prey. Externally, on either side of the vomerine teeth, are the mouth openings of the nasal passages. In the back of the mouth can be seen the opening of the *oesophagus.* Just in front of this on the floor and between the hinder fork of the tongue is a vertical slit, the *glottis* leading to the lungs. On the back part of the roof of the mouth on either side are the mouth openings of the *Eustachian tubes* each of which leads to the middle ear of its side.

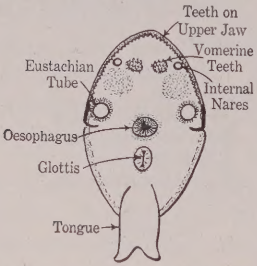

Teeth on Upper Jaw
Vomerine Teeth
Eustachian Tube
Internal Nares
Oesophagus
Glottis
Tongue

FIG. 240. — Mouth parts of frog.

Digestive System (Fig. 241). The *oesophagus* extends from the mouth into the abdominal cavity and connects with the *stomach* toward the left side of the body. The left end of the stomach is large and saccular, while the right end tapers off into the *duodenum.*

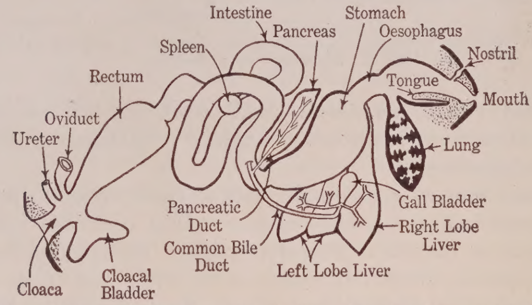

Intestine
Stomach
Pancreas
Oesophagus
Spleen
Nostril
Rectum
Tongue
Mouth
Oviduct
Ureter
Lung
Pancreatic Duct
Gall Bladder
Right Lobe Liver
Common Bile Duct
Left Lobe Liver
Cloacal Bladder
Cloaca

FIG. 241. — Diagram of digestive tract of frog. Associated organs are indicated.

The *pyloric valve* is between the stomach and duodenum. The duodenum is the first part of the *small intestine.* It receives the ducts from the *liver* and *pancreas.* The remainder of the *small intestine* is coiled and leads into the abruptly widening *rectum.* This connects with the *cloaca,* which is similar to the cloaca of the dogfish. From the ventral side of the cloaca originates a thin, bilobed cloacal (urinary) *bladder.* Urine passes into this from the cloaca. The *liver* is a large, dark red, three-lobed, gland lying under the stomach and part of the intestine ventrally. The *gall bladder* is in the liver on the right. From lobular ducts, bile collects in the gall bladder and from this, by the *common bile duct,* passes into the duodenum. The *pancreas* is a filmy white gland between the pyloric end of the stomach and the duodenum. Its secretions pass through the *pancreatic duct* into the bile duct and so into the duodenum. Digestion begins in the stomach and continues in the intestine, from which the digested food is absorbed into the blood.

Respiratory System. The skin is plentifully supplied with capillaries capable of absorbing oxygen from the water or air. The frog's body is always moist and the skin serves as an organ of respiration even in air. But the frog also has lungs (Fig. 241). The *glottis* leads into the short windpipe, from which originate, almost at once, the *lungs.* These are delicate sacs which lie on either side of the front end of the body cavity next the liver. The area of the inner surface is increased by the presence of small membranous chambers called *alveoli.* The walls of the lungs are rich in capillaries. The *larynx,* or voice-box, is between the glottis and the lungs. In it are the vocal cords, elastic membranous bands stretched across the larynx. The edges of these bands are vibrated by air expelled from the lungs thus producing the croaking sound. In breathing, the mouth, oesophagus and glottis openings are closed. The floor of the mouth descends. Air rushes into the mouth through the nasal passages. The external nostrils are closed, the floor of the mouth is raised and the air is forced into the lungs. When the muscles of the body wall contract, the air is forced out of the lungs into the mouth cavity and out through the nasal passages.

Excretory System. The *kidneys* (Fig. 242) are a pair of dark red bodies about two centimeters long and somewhat less than half a centimeter in diameter, located in the posterior part of the body cavity on the dorsal wall, on either side of the backbone. A small *ureter*, or urinary duct, passes from each kidney to the cloaca. On the ventral side of each kidney is a yellow linear-shaped body. This is the *adrenal*, a ductless gland. At the anterior end of each kidney is an adipose or *fat body*. These have yellow, light-colored, finger-like processes. It is thought that reserve food supplies are stored in these for use during the hibernating season and early spring. Through the kidneys are excreted primarily wastes of metabolism such as urea.

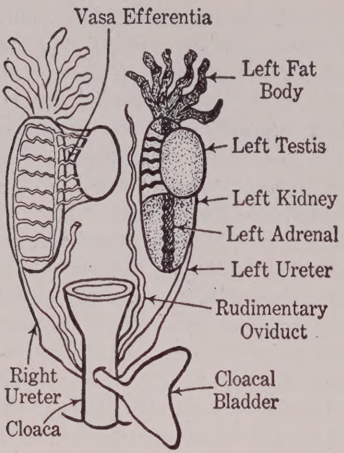

Vasa Efferentia
Left Fat Body
Left Testis
Left Kidney
Left Adrenal
Left Ureter
Rudimentary Oviduct
Right Ureter
Cloaca
Cloacal Bladder

FIG. 242. — Male reproductive and excretory systems of frog, ventral view. The left figure shows *vasa efferentia* from testis to kidney.

Reproductive System (Fig. 242). The sexes are separate. Sperm are formed in the *testes*. These are yellow bodies about a centimeter long and half as wide, situated underneath, and toward the front end of the kidneys. Each is connected with a kidney by a transparent membrane. In this membrane are very fine ducts, the *vasa efferentia*, through which sperm pass from the testis to the kidney. The sperm then pass through ducts in the kidney to the Wolffian ducts, or ureters, thence to the cloaca. Eggs are fertilized outside in the water. The ureter of the male thus serves as a *vas deferens*, that is, duct for conveyance of sperm.

In the early spring the *ovaries* (Fig. 243) of the female are enormously enlarged. They have the appearance of great

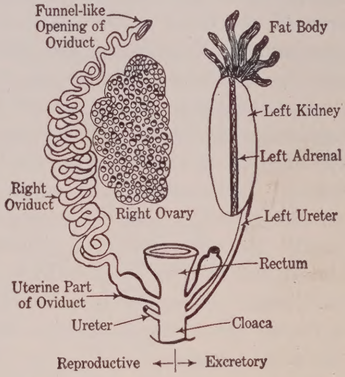

Funnel-like Opening of Oviduct
Fat Body
Left Kidney
Left Adrenal
Right Oviduct
Right Ovary
Left Ureter
Rectum
Uterine Part of Oviduct
Ureter
Cloaca
Reproductive ←|→ Excretory

FIG. 243. — Ventral view, female urinogenital system of frog. The left half of the reproductive system and right half of urinary system are omitted from the diagram.

masses of eggs. The eggs are budded off from the ovary into the body cavity. In the body cavity the ripe eggs are passed forward. At the front end of the body cavity they pass into the funnel-shaped anterior ends of the oviducts. The *oviducts* are long, very much coiled tubes, which pass on either side back to their entrance into the cloaca. In their passage through the oviduct, the eggs receive a coating of gelatinous material. During the day and night eggs continue to pass from the ovary back through the oviduct, collecting in a saccular enlargement, the *uterus*, at the posterior end of the oviduct. Eggs are laid in the early morning. The male clasps the female with his forelegs just behind her forelegs. This is kept up for several days. The eggs which have accumulated in the uterus pass into the cloaca, thence to the water outside. As this occurs the sperm are discharged over them and fertilization takes place. The gelatinous coating of the egg now swells. The fertilized egg, from which the embryo is to be formed, is a large cell containing a large amount of yolk, which is absorbed during development. It is surrounded by gelatinous material secreted by the oviduct. Frogs' eggs with their albuminous coverings are similar to hens' eggs without shell membranes or shells.

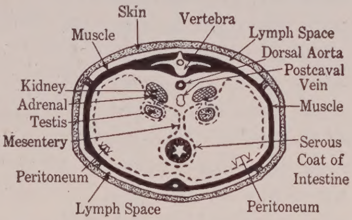


FIG. 244. — Cross-section of body of frog, showing peritoneum, mesentery and position of organs. Modified from Parker and Parker, in Holmes' *Biology of the Frog*, 4th revised edition, 1927, copyright, Macmillan Co. Reprinted by permission.

Membranes (Fig. 244). The inside wall of the body cavity is covered with a thin protecting membrane, the *peritoneum*. The *viscera* are suspended from the body wall along the dorsal area by similar thin, sheet-like membranes, the *mesenteries*. In these and near the stomach somewhat to the left side is a small red body, the *spleen* (Fig. 241). This is a lymph gland.

Blood (Fig. 245). The blood of the frog consists of (1) a liquid *plasma* containing water, salts, food and wastes; (2) *white blood corpuscles* (leucocytes) which are ameboid in form and activity, and which swallow invading microorganisms like Bacteria and so act as scavengers; and (3) *erythrocytes* or *red corpuscles* which are flat, oval-shaped, nucleated cells containing *hemoglobin*, which has a great affinity for oxygen and by virtue of which the red corpuscles transport oxygen from the lungs and skin to the tissues.

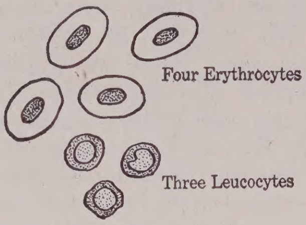

Four Erythrocytes
Three Leucocytes

Fig. 245. — Blood cells of frog.

Circulatory System (Figs. 246 *A* and *B*). The *heart* is triangular in shape. It is located just under the pectoral girdle. Posteriorly is the thick, muscular *ventricle*. Anterior to this are the right and left *auricles* which are not so muscular. Between the two auricles on the ventral side is the thick tubular *truncus arteriosus* which arises from the *ventricle*. The incoming venous blood empties into a thin-walled sac, the *sinus venosus*, connected with the right auricle. *Arteries* carry blood *away from* the heart while *veins* carry blood *to* the heart. Capillaries are thin-walled net-works of fine vessels interposed between arteries and veins and ramifying among the various tissues.

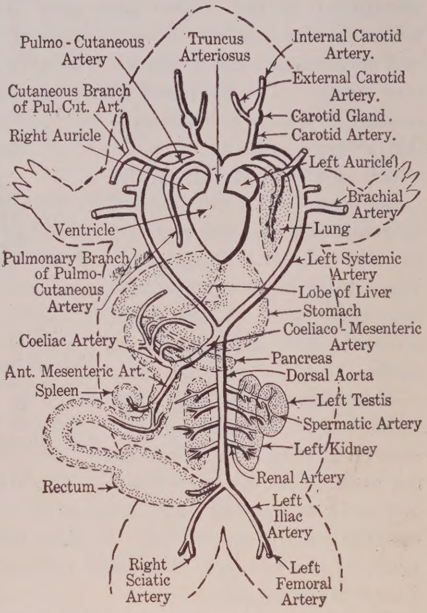

Pulmo - Cutaneous Artery
Truncus Arteriosus
Internal Carotid Artery.
External Carotid Artery.
Cutaneous Branch of Pul. Cut. Art.
Carotid Gland.
Carotid Artery.
Right Auricle
Left Auricle
Brachial Artery
Ventricle
Lung
Pulmonary Branch of Pulmo-Cutaneous Artery
Left Systemic Artery
Lobe of Liver
Stomach
Coeliaco-Mesenteric Artery
Coeliac Artery
Pancreas
Ant. Mesenteric Art.
Dorsal Aorta
Spleen
Left Testis
Spermatic Artery
Left Kidney
Renal Artery
Rectum
Left Iliac Artery
Right Sciatic Artery
Left Femoral Artery

Fig. 246 *A*. — Ventral view, arterial circulation of frog. The shaded organs indicated are *shadow outlines*.

The principal arteries are: (1) the *carotids*. Each one of this pair arises from a branch of the *truncus arteriosus* and passes forward, supplying the brain, eye, tongue and other parts of the head. (2) The *pulmo-cutaneous*. These also each originate as a branch of the *truncus arteriosus*. The common pulmo-cutaneous

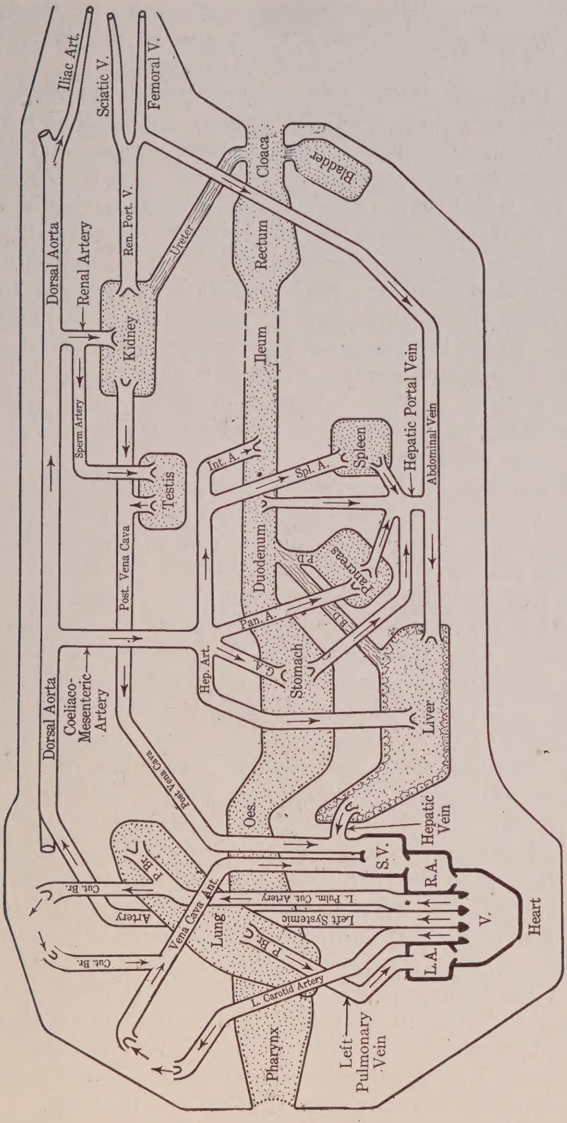

Iliac Art.
Sciatic V.
Femoral V.
Cloaca
Bladder
Dorsal Aorta
Renal Artery
Ren. Port. V.
Ureter
Rectum
Kidney
Ileum
Hepatic Portal Vein
Abdominal Vein
Sperm Artery
Testis
Int. A.
Spl. A.
Spleen
Post. Vena Cava
Duodenum
P.D.
Pancreas
B.D.
Pan. A.
Dorsal Aorta
Coeliaco-Mesenteric Artery
Hep. Art.
G.A.
Stomach
Liver
Post Vena Cava
Oes.
Hepatic Vein
S.V.
R.A.
P. Br.
Cut. Br.
L. Pulm. Cut. Artery
Artery
Left Systemic
V.
Heart
Vena Cava Ant.
Lung
P. Br.
Cut. Br.
L.A.
L. Carotid Artery
Pharynx
Left Pulmonary Vein

FIG. 246 *B*. — Scheme of arterial and venous system of frog.

soon divides into (*a*) the *pulmonary*, which passes to the lungs, and (*b*) the *cutaneous*, a branch which goes to the skin. They carry blood to the lungs and skin to be oxygenated.

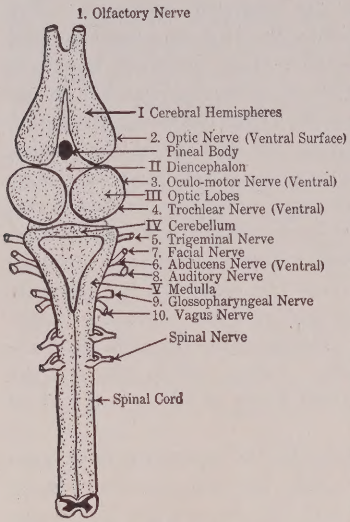
(3) Between the carotid and pulmo-cutaneous on either side and arising as a branch of the truncus arteriosus is a third artery, the *systemic*. Each systemic passes dorsally and posteriorly *around the alimentary tract. They unite above the intestine to form the* (4) *dorsal aorta.* This passes posteriorly, giving off large branches to various organs. At the posterior end of the body it divides into the two (5) *iliac arteries*, each of which subdivides into the arteries of the hind leg. Each systemic artery before it unites with its fellow gives off important branches to the head, backbone and arm. At the junction of the systemics with the dorsal aorta arises the (6) *coeliaco-mesenteric*, which gives important branches to the liver, stomach, pancreas, spleen and intestine. Small branches from the dorsal aorta supply the muscles of the body wall, the ovaries, testes and kidneys.

The blood from the lungs returns through the pulmonary veins to the left auricle. A large *anterior vena cava* (jugular) vein on either side returns venous blood from the head to the sinus venosus. The single *posterior vena cava* returns blood to the sinus venosus from the liver, from the kidneys, ovaries, etc. Certain veins from the hind legs pass into the *renal portal* veins which carry blood to the kidneys. This blood passes via the *post cava* to the *sinus venosus.* Other veins from the hind legs unite to form the *abdominal* vein. This vein runs forward along the mid-ventral line of the abdominal wall and passes into the liver. Blood from the stomach, intestine, spleen and pancreas passes into the *hepatic portal vein* which joins the abdominal vein. The liver is connected in turn with the *hepatic veins*, which join the *post. vena cava*, which connects with the adjacent *sinus venosus*. Thus the blood returning to the heart from the hind legs passes through *either* the *renal-portal* system or the *hepatic-portal* system to the heart. Wastes of metabolism such as urea are removed from the blood as it circulates through the kidneys. These substances excreted by the kidneys pass into the ureters, and thence into the cloaca and from this to the cloacal bladder from which they are discharged later and out the cloacal opening, *i.e.*, the anus. The hepatic-portal system carries blood containing absorbed food and certain secretions into the general circulation of the body.

From the sinus venosus the blood passes into the *right auricle.* The blood from the lungs returns to the *left auricle* via the *pulmonary* veins at the same time. Both auricles contract simultaneously and both bloods are discharged into the ventricle filling it. Valves between auricles and ventricle prevent the blood from returning to the auricles when the ventricle contracts. The ventricle contracts, forcing blood into the truncus arteriosus and into its right and left branches. Each of these, as shown, has three branches. The opening to the truncus arteriosus is rather to the right of the ventricle, so that when the latter contracts, the blood on that side of the ventricle is driven out and enters the *pulmo-cutaneous artery*, thus transporting *un-oxygenated* blood to the lungs and skin. The blood filling the mid-portion of the ventricle follows. This blood is a mixture (slight) of unoxygenated and oxygenated blood which passes into the *systemic* arteries and thence throughout the body behind the head. Next the blood on the left side of the ventricle (oxygenated, and just returned from the lungs) passes forward into the *carotid* arteries supplying the head including the central nervous system. Valves within the truncus aid in the sorting out of the different kinds of blood referred to above.

We shall find a more effective device for the separation of oxygenated and unoxygenated blood in reptile, bird and mammal hearts. Blood carried away from the heart by the arteries transports soluble food compounds, salts and oxygen into the capillary network present in the various tissues. Some of these products diffuse from the thin-walled capillaries into tissue spaces and so near to the tissue cells. The fluid in the tissue spaces is called *lymph.* It resembles blood without red blood cells. Tissue cells absorb water, salts, oxygen and foods from lymph and also discharge wastes into it. A constant current of blood flows from arteries, through capillaries into veins and hence back to the heart. But the lymph is also constantly finding *its* way slowly through lymph vessels and veins back to the heart. *In the frog,* the lymph vessels communicate with lymph sinuses, some of which are located just beneath the skin. The skin seems to be loosely fitted to the body wall. The sinuses noted above are subcutaneous spaces somewhat separated from each other by fibrous partitions which connect the skin with the underlying tissues. Two pairs of dorsal *lymph hearts,* one pair located above the pectoral girdle, and one pair near the hinder end of the urostyle, *pump* the lymph into veins and so back into the general circulation.

Nervous System. The nervous system is divided into three regions (Fig. 247): (1) the *central nervous system* composed of brain and spinal cord; (2) *peripheral,* composed of nerves branching into the body from the central nervous system; (3) *sympathetic system.*


1. Olfactory Nerve
I Cerebral Hemispheres
2. Optic Nerve (Ventral Surface)
Pineal Body
II Diencephalon
3. Oculo-motor Nerve (Ventral)
III Optic Lobes
4. Trochlear Nerve (Ventral)
IV Cerebellum
5. Trigeminal Nerve
7. Facial Nerve
6. Abducens Nerve (Ventral)
8. Auditory Nerve
V Medulla
9. Glossopharyngeal Nerve
10. Vagus Nerve
Spinal Nerve
Spinal Cord

Arabic Numbers Refer to Cranial Nerves
Roman " " " Parts of Brain

FIG. 247. — Dorsal view of frog's brain. Cranial nerves also indicated.

(1) The brain possesses two large *olfactory lobes.* Behind these is the *cerebrum,* composed of two *cerebral hemispheres.* Next comes the small *between-brain* or *diencephalon,* which has the *pineal gland* above and the *pituitary gland* (ductless) below; behind this are the *optic lobes* and behind these, the small transverse *cerebellum.* Between this and the *spinal cord* is the triangular *medulla* with the *fourth ventricle* on the dorsal side.

(2) The frog has ten pairs of *cranial nerves.* Of these the first pair are the *olfactory,* which carry sensory impulses of smell to the brain, the second or *optics* carry sensory impulses of vision to the brain, the eighth or *auditory* carry sensory impulses from the ear (auditory and equilibrium) to the brain. The third pair, *oculomotor;* the fourth, *trochlearis;* and the sixth, *abducens,* all carry motor impulses from the brain to muscles of the eye.

The fifth, *trigeminal,* is a large nerve which contains both sensory and motor-fibers; *chiefly sensory* from skin of face, mouth and tongue and motor to lower jaw muscles.

The seventh is the *facial,* also a large compound nerve. It carries *chiefly motor* impulses to the muscles of the face. The ninth is the *glossopharyngeal* and the tenth is the *vagus,* both compound nerves, *i.e.,* sensory and motor. The ninth innervates the pharynx and tongue, while the tenth is interesting and so called because it *leaves the head and " wanders " back into the body*, supplying lungs, heart, stomach and intestine. Similar cranial nerves are found in all Vertebrates. Higher Vertebrates have two more pairs of cranial nerves, *i.e.*, twelve.

There are ten pairs of *spinal nerves* arising from the spinal cord, which is inclosed in the bony spinal canal above the bodies of the vertebrae. Each spinal nerve originates from the cord by two roots, a *dorsal root*, which carries sensory impulses *into* the cord from the periphery, and a *ventral root*, which carries motor impulses *out of* the cord to body muscles. The two roots unite outside the cord to form the *spinal nerve*, some of whose fibers originate in sensory organs of the body wall while other fibers terminate in motor end-plates in muscles. (See Fig. 322.) The largest spinal nerves are the *brachials*, which run to the arms, and *sciatics*, which supply the legs. In each of these cases, more than one pair of spinal nerves cooperate to form the nerves of the legs.

(3) The *sympathetic system* is collateral to the *central system*. It possesses two main, thread-like ganglionated trunks, one on either side of the backbone. Each sympathetic ganglion is connected to a spinal nerve ganglion. Nerves from the sympathetic system are distributed to the heart, liver, lungs, kidneys, head, alimentary tract and other internal organs and blood vessels.

Sense organs. The skin of the frog contains sense organs activated by temperature changes, by contact, chemical and light stimuli. The tongue and membranes lining the mouth cavity contain taste sense organs, and the olfactory nerves end in among cells forming the lining membrane of the nasal passages. The eye has the same general structure as that of other Vertebrates (Fig. 338). The ear contains the sense organ of hearing and of equilibrium. The ear of the frog differs in detail from that of other Vertebrates such as the Mammal (Fig. 337) but the same basic structural plan is evident. Three differences are noted here; (1) the frog has no external ear; (2) Sound wave vibrations are carried across from the tympanum to the inner ear by the rod-like columbella instead of the chain of bones of the Mammals (Fig. 337); (3) The portion of the inner ear which contains the sense organ of hearing is an irregular, oval-shaped sac rather than the spiral cochlea of the Mammal.

Development (Fig. 248). From the developing egg of the frog hatches a tadpole. This is a fish-like form. It has gills, and swims by means of a long tail. It feeds mostly on vegetable matter. Two sets of gills are formed. First, *external gills* which project out from the walls of the pharynx. These are replaced by *internal gills* more like those of fishes. Hind limbs appear as buds and gradually increase in size and perfection. The front limbs appear later and are first formed inside of a temporary sac called the *operculum.* The operculum incloses a sort of atrial chamber about the sides and floor of the mouth. Water taken into the mouth passes out through the gill slits into the atrial chamber and from this to the outside. The developing front limbs break their way through the operculum. The tail is gradually absorbed and lungs appear. With the formation of these, the circulatory system develops new arrangements also. It changes from a fish-like type to the adult frog type. With the assumption of land existence the frog moves about and breathes like a land animal. The changes connected with the transition from the aquatic fish-like form to that of a land-inhabiting frog constitute *metamorphosis.*

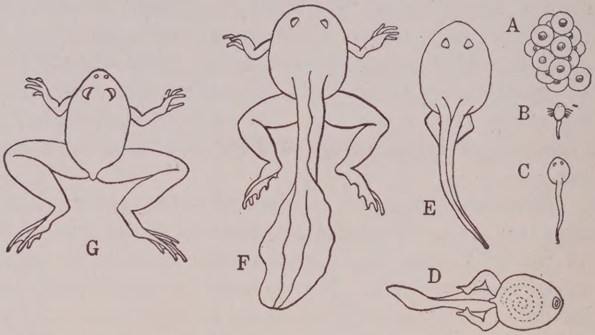


FIG. 248. — Development of frog. *A*, egg cluster; *B* and *C*, young tadpoles; in *D* and *E*, hind legs appear; in *F*, front legs also; in *G*, tail has been absorbed. From Paulmier — Bull. N. Y. State Museum.

Classification

There are about a thousand species of Amphibians. They form a transitional group between the Fishes and land Vertebrates. The name of the group signifies that they live in the water and on land.

Order 1. Apoda or Gymnophiona. A few species are limbless and snake-like in form. These are called *Coecilians.* They are tropical burrowing animals with poorly developed eyes. The tail is very short and there are transverse rows of plates in the skin.

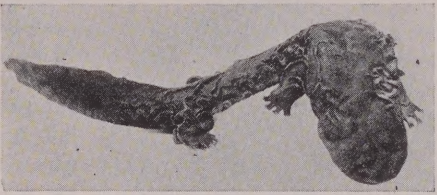


FIG. 249. — Cryptobranchus — Hellbender. (Amer Mus. Nat. Hist.)

Order 2. Caudata or Urodela. In these the tail persists throughout life. The external gills and gill clefts may also persist throughout life. The limbs are small and weak. They include salamanders, newts and the mud-puppy, Necturus.

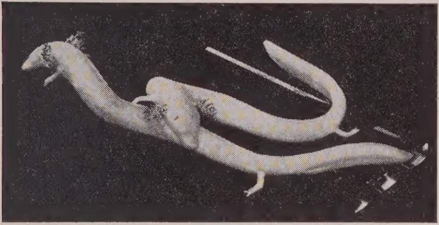


FIG. 250. — Amphiuma — Congo eel. (Amer. Mus. Nat. Hist.)

Cryptobranchus maximus is the largest living Amphibian. It is found in Japan and may grow to be over three feet in length. *Cryptobranchus alleghaniensis* (Fig. 249) is the hellbender found in streams in the eastern part of the United States. It attains a length of about eighteen inches. The Congo eel (Fig. 250), *Amphiuma means,* is eel-shaped and has two pairs of small limbs far apart. *Ambystoma tigrinum* (Fig. 251), about six inches long, breeds in the larval form if metamorphosis is prevented. Such a larval form of *Ambystoma* was formerly thought to be a separate species. It was called the *Axolotl. Desmognathus fusca* lives in dark, moist

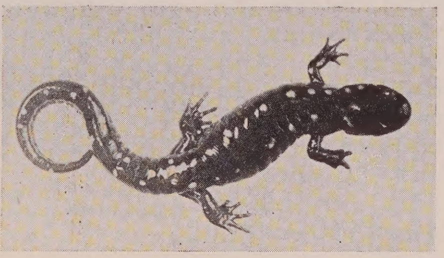


FIG. 251. — Ambystoma tigrinum. (Amer. Mus. Nat. Hist.)

places. It has no lungs or gills. Two long strings of eggs are laid by the female, and wound about her body and there they remain until hatched.

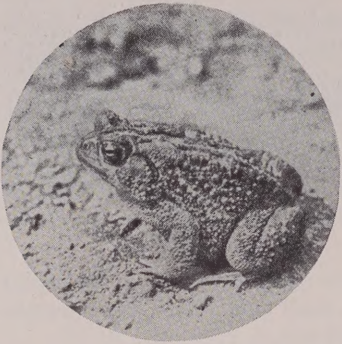


FIG. 252.—Bufo—Common toad. (Amer. Mus. Nat. Hist.)

Order 3. The Salientia or Anura. These are the frogs and toads and include about nine hundred species. They have no tail, nor do the adults possess gills. *Bufo*, the toad (Fig. 252), has a "warty" skin. The secretions of the skin glands of some tropical species are very poisonous. Common toads destroy garden insects in great numbers and so are valuable aids to agriculture. Toads breed in the water. Eggs are laid in strings. Development from egg to adult condition takes but a few weeks. At the end of this time, the very small toads leave the water.

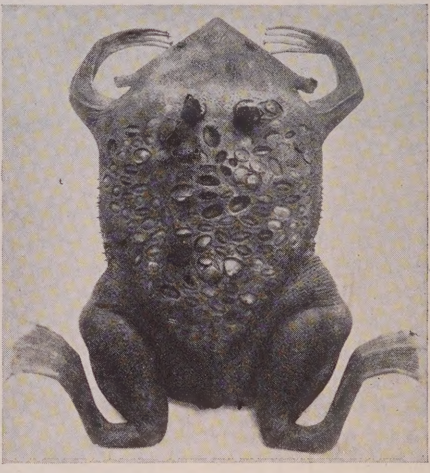


FIG. 253. — Pipa americana — Surinam toad. Note young toads in sacs on back. (Amer. Mus. Nat. Hist.)

Very unique and effective methods of protecting and caring for eggs and young are found among the Amphibia. For example, the female Surinam toad (Fig. 253) (Dutch Guiana) by everting the cloaca can deposit the eggs upon the soft, spongy tissue of her back, where the young develop. The male of *Alytes obstetricans* (Germany) winds eggs about his hind legs and keeps them there until it is time for them to hatch, when he moves to water. While most Amphibia are oviparous, yet *Salamandra atra* (Switzerland) is viviparous, for the two developing young are kept in the oviduct until after metamorphosis.

Fossil Amphibia. *Stegocephalia* were large, tailed and salamander-like forms which flourished in the Carboniferous age. They had large bony plates on the head and other parts of the body. No more ancient forms possessing the typical land type of limb have been found.

Phylogenetic Relations of Amphibia. Many zoologists consider that the ancestors of the Amphibia were Stegocephalia which were derived from the ganoid fishes, of which the sturgeon is a *modern* example. There is evidence also that these primitive fishes (Ganoids) were the ancestors of the Teleostomi on the one hand, and the Dipnoi on the other. The Elasmobranchs are even more primitive than the Ganoids. The Caudata more closely resemble the Stegocephalia in form while the Salientia are more highly specialized.

The Stegocephalia appear also to have given rise to the Reptilia.

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CHAPTER XVI

PHYLUM CHORDATA — PART III

SUB-PHYLUM VERTEBRATA. CLASS IV — REPTILIA

Characteristics. The word *reptile* is derived from the Latin verb " repere," meaning to *creep* or to *grovel.* The name applies not only to the *snakes* but to lizards, turtles, tortoises, crocodiles and alligators as well, for these are included in the class *Reptilia.* The body is covered with epidermal scales; the toes if present have claws; the gills are limited to the embryonic period while the respiratory organs of the young after *hatching* are lungs. Fertilization is internal; the eggs are few and of considerable size, resembling those of birds, with yolk, albumen and shell; development takes place outside the body of the mother, *i.e.,* reptiles are oviparous; the embryo develops rapidly, and at hatching the young break the shell. Reptiles are essentially land forms and are the first Vertebrates to take up permanent life upon the land.

Reptilia were once the dominant land Vertebrates. This was during the Mesozoic Era, a period estimated to have lasted for thousands of centuries. There were then many more types than at present, and primitive Birds and Mammals were just emerging. Some Mesozoic Reptilia attained gigantic size.

Anatomically, reptiles are similar in many respects to the Amphibians; as, for example, in their circulatory systems and in limb structures. In other respects they are dissimilar; as, for example, reptiles possess radically modified excretory and reproductive systems. Birds and Mammals retained certain features of the reptilian advance.

Amnion and Allantois. Embryonic respiration is carried on through a foetal sac called the *allantois,* and the embryo is protected in a membranous sac called the *amnion.* (See page 348.) Reptiles, Birds and Mammals are alike in the possession of a foetal amnion and have therefore been called *Amniota,* while Fishes and Amphibians are known as *Anamniota* since they lack it.

The Anamniota develop in water. However, this is also true in a way of the Amniota, for the amnion is filled with a watery fluid, so that, as Walter has observed, "*every Vertebrate passes its early life submerged in water.*"

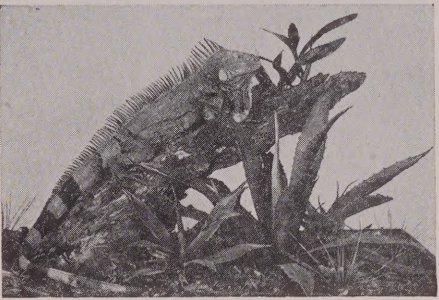

FIG. 254. — Iguana tuberculata. (Amer. Mus. Nat. Hist.)

Classification

There are five groups of Reptilia living today.

Order 1. Rhyncocephalia. Many fossil forms are included in this order of which but one living species remains, namely, Sphenodon found in New Zealand. It is lizard-like in appearance and is unique in the possession of a third but degenerate "eye" in the roof of the skull. This form is so rare and of such great scientific interest that it is at present under governmental protection.

Order 2. Lacertilia. These are lizards. They have two pairs of legs and a tail. They are most numerous in warm countries, preferring a warm, sunny, dry habitat. The *Iguana* (Fig. 254) of tropical America is large and ferocious in appearance, but actually is otherwise and is used as food. *Phrynosoma,* from the dry lands of our southwest, is called the 'horned toad' but is not an amphibian. *Heloderma,* the Gila Monster (Fig. 255), is found in the same locality and is a large, brightly colored, sluggish and forbidding-looking lizard and said to be poisonous, which is not true of lizards as a class. Many lizards move swiftly when disturbed.

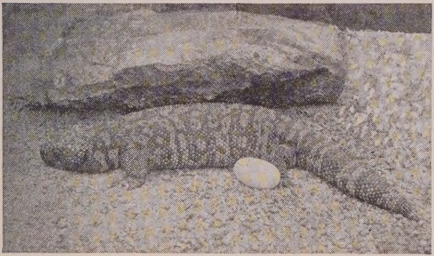

FIG. 255. — Heloderma — Gila Monster with its egg. (Amer. Mus. Nat. Hist.)

Order 3. Ophidia or Serpents. These forms have no limbs or limb girdles although some, such as the python, retain vestiges of the limb girdles. On the mid-ventral line anterior to the anus is a row of large scales to the inner ends of which are attached the outer ends of ribs. The outer edges of the scales act as fulcra of levers, of which the ribs are a part. The levers are operated by muscles of the body wall, forming organs of locomotion. The absence of limbs and the sinuous nature of the backbone enable snakes to glide through small passageways. They seem to 'flow' along the ground, and the rapid movement in the absence of apparent organs of locomotion startles most observers.

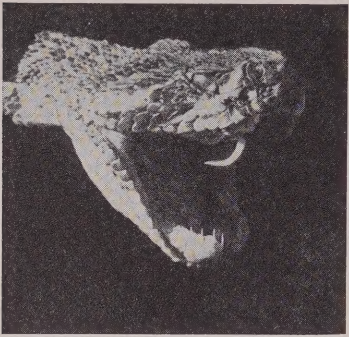

Fig. 256. — Head of rattlesnake showing 'poison' fang. (Amer. Mus. Nat. Hist.)

There is no ear drum and the sense of hearing is poor. The tongue is protrusible and is probably used to receive stimuli other than those of taste. Teeth are sharp and pointed backward to prevent prey from escaping. In poisonous snakes there are grooved teeth or the latter have ducts through which toxins from the poison glands are introduced into the blood stream of the victim (Fig. 256). The apparatus *works* like a hypodermic syringe. Many of the bones of the jaw apparatus are movable so that snakes can swallow comparatively large animals. The vibrating *rattle* of *Crotalus*, the North American Rattlesnake, warns the oncomer of danger ahead. There are a number of species of American rattlesnakes. However, but few of all types of American snakes are poisonous. On the whole,

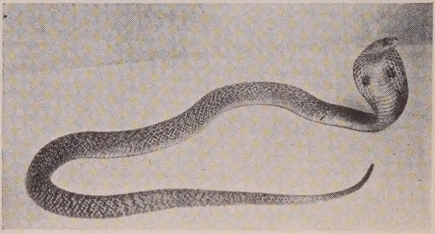

Fig. 257. — Naja — The cobra. Photo by N. Y. Zoological Park.

snakes are useful to man in destroying harmful insects and rodents. The Cobra (Fig. 257) of India, China and the Malay Archipelago is vicious and deadly. It causes the death of thousands of natives annually. Today the rapid development and wider use of antivenom sera for snake bite is saving many lives.

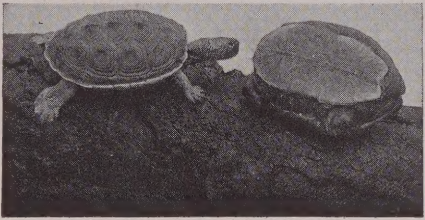
FIG. 258. — Malacoclemmys — Diamond-back terrapin. (Amer. Mus. Nat. Hist.)

Order 4. Chelonia. These are turtles, which are aquatic forms, and tortoises, which are land forms. They have an exoskeleton of horny epidermal shell which covers a deeper layer of bony plates. The soft parts are inclosed in a protective armor and only the limbs, tail, head and neck venture outside the shell when the animal is moving about. The diamond-back terrapin (Fig. 258) is highly prized as a food product, and successful *farming* experiments have been developed by the U. S. Bureau of Fisheries. The giant land tortoise *Testudo* (Fig. 259) of the Galapagos Islands lives to a great age and is a sort of *living fossil.* The giant form among the turtles is *Sphargis*, the leathery turtle found along the coasts of Florida and Brazil. Specimens weighing over a thousand pounds have been taken.

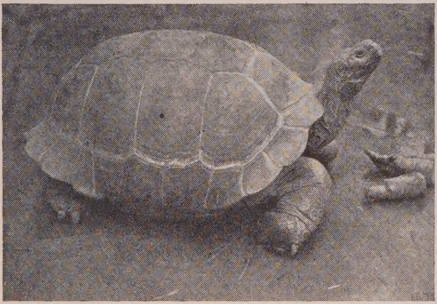
FIG. 259. — Testudo — Giant tortoise. (Amer. Mus. Nat. Hist.)

Order 5. Crocodilia. These are large reptiles, including crocodiles and alligators (Fig. 260). They live in and out of the water in or near the tropics. The nostrils are at the tip of the long snout and farther back are the protruding eyes, enabling the animal to remain in the water with the body immersed and almost invisible but on the watch for prey.

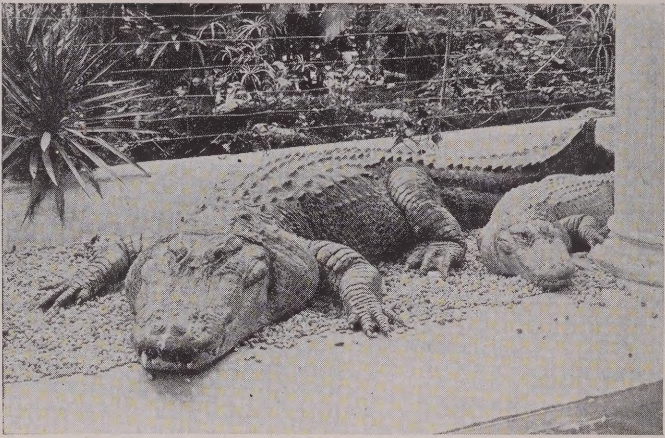

FIG. 260. — Alligator. Photo by N. Y. Zoological Park. Courtesy N. Y. Zoological Society.

Most reptiles have two distinct auricles and one ventricle, as have the Amphibians. However, in reptiles there is a *perforated* partition dividing the ventricle into a right and left portion. This device serves fairly well to keep separate the oxygenated from the unoxygenated blood in the heart. In the Crocodilia the partition in the ventricle is more complete, so that they have a right and left ventricle, as have Birds and Mammals.

FIG. 261. — Oreortyx pictus — California quail.

CLASS V — AVES

Characteristics. Birds and Mammals are the most highly organized Vertebrates. Both had reptilian ancestors. A bird (Fig. 261) is a *feathered* Vertebrate. Birds successfully and easily navigate the air. They are warm blooded and the blood has a constant temperature, somewhat over

100° F. The fore-limbs are wings (Fig. 262). The skeleton of the wing shows fundamental resemblances to the limb plan of the Amphibian and Reptile but with adaptive modifications. The bones of the shoulder girdle, wrist and hand are modified to form the wing skeleton. The broad surface of the wing is useful not only as a propeller but also as a support in the air. The pectoral muscles are enormously enlarged for the operation of the wings of flying birds and the breast bone is increased in size to afford a larger surface area for the attachment of these greater muscles.

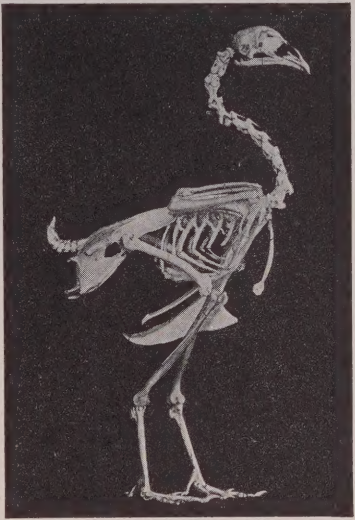
Fig. 262. — Skeleton of common fowl — Gallus.

The long tail of other Vertebrates is represented in birds by a few vertebrae which form a short stump. There is a movable neck. Birds are bipedal and the structure of the hind limb is modified for this method of body support or locomotion. Bi-pedal land locomotion is necessitated by reason of the fact that the front limbs are used for flight. The entire skeleton is knit into the compact, light frame of a flying machine. Many of the bones contain air spaces. There are no teeth in the jaws, which instead are encased in horn. The beak is a very useful tool. Food passes from the oesophagus into the thin, saccular crop in which it is softened. From the crop it passes into the glandular portion of the *stomach*, where gastric juice is added to the food. Behind this is the thick, muscular gizzard whose contractions, aided by small pebbles swallowed with food, act like a mortar and pestle or mill in grinding the food. Behind the gizzard is the small intestine, where further digestion takes place and where the simplified food compounds are absorbed into the blood stream. The short large intestine is connected posteriorly with the cloaca. A large liver, a pancreas and ductless glands are present as in other groups.

The blood consists of plasma, white corpuscles and nucleated red-blood corpuscles. The heart has two auricles and two ventricles. The venous body blood enters the right auricle and goes into the right ventricle; thence to the lungs, thence to the left auricle then to left ventricle and thence into the *single* aorta, from which it is distributed throughout the body. There is a long windpipe. At the junction of the windpipe with the bronchi is the *syrinx*, the voice-box of birds. The lungs are composed of multitudes of minute alveolar sacs connected by very fine bronchial tubes to larger branches and so to the windpipe. A much greater area of respiratory surface is thus provided for than is the case in lower groups. There is a special system of air reservoirs connected with the lungs of birds. When filled, they form inflated spaces in the body cavity. Ducts from these extend into the bones of the limbs. The mechanism for the exchange of respiratory gases is of a high order. The greater respiratory

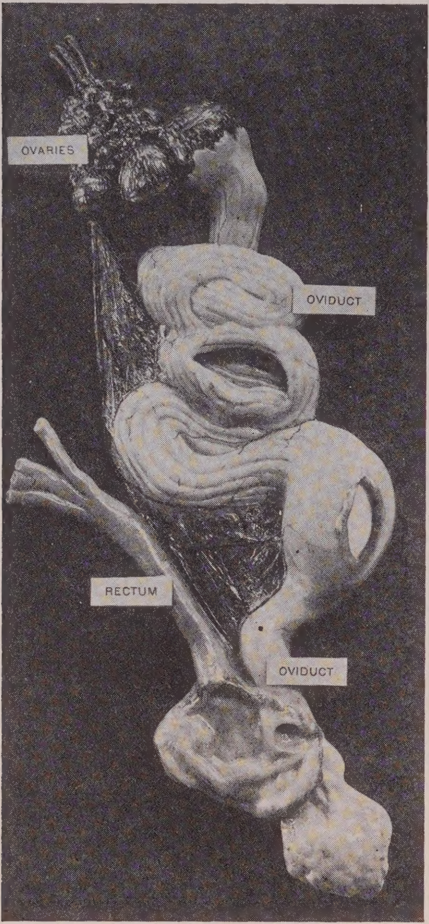

FIG. 263. — Reproductive organs of hen. (Amer. Mus. Nat. Hist.)

surface involves a greater and more rapid exchange of respiratory gases and this in turn means higher rate of metabolism.

This is also true of Mammals. Birds and Mammals live more intensely than do the lower forms. Birds are on a par with some of the insects in sustained persistence of active movements.

There is no urinary bladder in birds. The urine is semi-solid. Some water is excreted with expirations. The right ovary and oviduct usually degenerate (Fig. 263). There is usually no special organ of copulation, but nevertheless copulation takes place and fertilization is internal. The hen's egg (Fig. 264) hatches in about 21 days and that of the pigeon in about 14. During the *incubation* period the eggs are kept at a temperature of about 100° F. by the warm body of the female bird, as a rule, although in some cases both mates take turns in performing this function. After hatching, the young birds are soon able to forage for themselves. The sense of hearing is highly developed and the visual sense still more so. The cerebral hemispheres are highly developed although the cortical surface is smooth and not convoluted as in many Mammals. Birds resemble reptiles in the possession of an amnion, allantois, large-yolked eggs with shell, cloaca and scales on the legs. Some of the differences have been noted above. Birds are exceptionally uniform in general structure. Differences are largely in details. On this account it is difficult to subdivide the group into well-defined differentiated types.

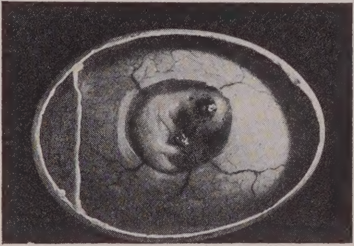

FIG. 264. — Ten day old chick embryo. (Photo by Amer. Mus. Nat. Hist.)

Classification

There are two great subdivisions, A. Archaeornithes and B. Neornithes.

Sub-class 1 — Archaeornithes. These are represented by a single fossil species, *Archaeopteryx lithographica.* Only two specimens have ever been found. These were taken from Solenhofen lithographic stone in Bavaria. This rock belongs to the Jurassic Period. Archaeopteryx was about the size of a crow and the body was covered with feathers as in modern birds. It had small, uniform teeth in both jaws, twenty-three vertebrae in the tail and each vertebra possessed a laterally placed feather on either side, forming a large, flat tail. The ends of the second, third and fourth digits of each wing were *clawed.* The bird probably used all four legs in climbing trees. A study of the structure of Archaeopteryx indicates that it is intermediate between reptiles and modern birds. Its discovery proved that birds appeared during the Mesozoic Era.

It is considered of more than passing significance that a modern bird belonging to the next sub-class possesses certain *primitive* features. The young hoactzin of British Guiana has claws on its wings and uses both pairs of limbs in climbing.

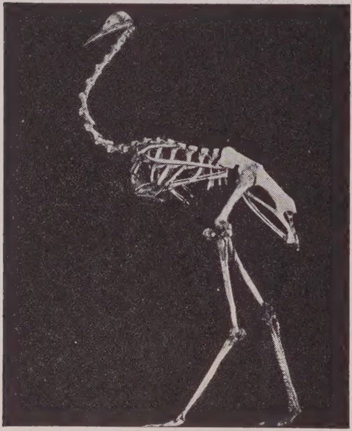

FIG. 265. — Skeleton of ostrich.

Sub-class 2 — Neornithes. These are modern birds. There is a short tail composed of a few fused vertebrae, around which the tail feathers are arranged like a fan. A few extinct forms had teeth. Two groups are distinguished.

Division I. Ratitae. These are large birds in which the wings are of small size or are absent. Wing muscles are small and weak and the sternum has no keel. On the other hand, the hind limbs are large and very strong. Ratitae are walkers or runners and distinctly terrestrial in habit. Ostriches (Fig. 265) are native in Africa, southwest Asia and South America. The cassowary (Casuarius) and emu (Dromaeus) are found in Australia and the kiwi (Apteryx) in New Zealand. The moa (Dinornis), a very large, wingless bird, has become extinct within the last five hundred years. Moas lived in New Zealand, and some of them were ten feet high with enormous legs.

Division II. Carinatae. These birds are for the most part equipped for flight with well-developed wings and wing muscles. Familiar birds such as the robin, sparrow, bluebird and eagle belong to this group. No separation into orders will be attempted here.

General Remarks. The size of the egg is related to the size of the bird. The egg of extinct Aepyornis was about 150 times that of the hen. The egg of the moa was nine inches in diameter and a foot in length. Song birds, as a rule, are naked, blind and helpless at hatching, while young chicks are covered with feathers at *birth* and are quite active a few hours later. Birds usually molt their old feathers after the breeding season and grow new ones to replace the old. The ptarmigan (Fig. 266) molts three times a year. It is white during the winter's snow; mottled brown in the spring and gray after the breeding season.

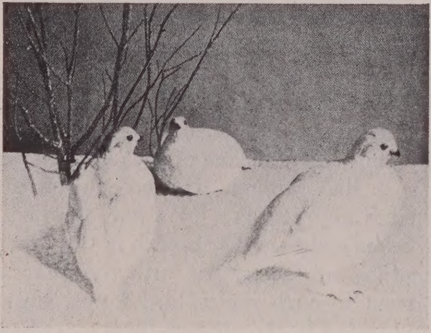

FIG. 266. — Ptarmigan in winter. (Amer. Mus. Nat. Hist.)

The migration of birds is not well understood. Notwithstanding the variations in weather from year to year, birds keep a regular schedule. Some come back to the same nest year after year. They fly day and night, over land and sea and for long distances. Food conditions, temperature and problems of rearing the young appear to be factors concerned with migration. Some birds exhibit the phenomenon of courtship prior to or during the mating season. Males are often highly colored and plumed while females are plain in appearance. Darwin thought that the highly decorative feathering of the male was brought about by a sort of selection. He maintained that the female selected the " handsomest " males and that generations of this so-called *sexual selection* produced the marked differences between the sexes. He attributed sexual dimorphism among insects to sexual selection, also.

Domesticated birds produce for man an income of millions of dollars annually. The ancestor of the common fowl was probably *Gallus bankiva*, the jungle fowl of India. Domestic pigeons have been likewise produced from the wild rock-pigeon, *Columba livia*, of Europe, Asia and China; domestic geese from the wild *Anser anser* of England and most of the ducks from the wild mallard, *Anas boca.* Birds have, as has been said, a structural similarity to reptiles. Huxley called birds "glorified reptiles." The biologist concludes that birds had reptilian ancestors, but they have long since diverged and advanced from them. From sluggish, cold-blooded, scaly and, to most people loathsome, reptiles, have evolved the birds, active, warm-blooded, beautifully feathered creatures. The mental attitude of the average man toward Birds is the antithesis of his feelings toward Amphibians and Reptiles.

Phylogeny. From the Stegocephali arose the reptiles, probably by more than one line of evolution, as suggested by the following: (*a*) A line through Rhyncocephalian-like forms to the present snakes and lizards; (*b*) a line of which one branch ends in the Chelonia and another branch in the Crocodiles which, of all extant reptiles, are associated with the Dinosaurs. But this line continued through reptile-bird forms, suggested by Archaeopteryx, and ended in the modern birds. (*c*) Still another line of reptiles evolved through primitive Theromorpha, more mammal-like than reptilian, and ended in the Mammals. See Appendix B.

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CHAPTER XVII

PHYLUM CHORDATA — PART IV

SUB-PHYLUM VERTEBRATA. CLASS VI — MAMMALIA

General Characteristics. Many of the Mammals surpass all other animals in supremacy over nature. The very name of the group, given by Linnaeus, carries with it reference to a phenomenon which is in no small sense responsible for the higher development of these forms. This is the process of nourishing the young by milk produced by the *mammary glands* of the mother. Related with this is the fact that there is a vital connection between the young and the mother within the latter's body from the time of egg fertilization to birth of that offspring. The helpless newborn are not only at first nourished by food formed in the body of the mother, but are later watched over by the mother and trained in the ways of life. Mammals are also distinguished by the presence of hair on the surface of the body. The temperature of the blood is about 98° F. and is quite constant, *i.e.*, independent of temperature changes in the external world. This insures, on the whole, a continuous condition of activity, shared in only by the birds. This makes it possible for Mammals and Birds to conquer the temperate and cold regions of the earth. Feathers and fur are an aid to this end.

Mammals are four-legged animals. They have a neck and a tail. The skin possesses oil glands and sweat glands. A muscular partition, the diaphragm, separates the heart and lungs from the viscera and is important in respiration. The cerebral hemispheres are very prominently developed and in some forms possess a convoluted cortex which permits the possession of a greater number of nerve cells. Posteriorly there is one opening for the intestine, *i.e.*, the anus, and a second opening for the urino-genital systems. The heart is four-chambered as in birds. The lungs consist of a multitude of little air sacs or alveoli connected with respiratory ducts which in turn are connected with the trachea. The ureters from the kidneys carry urine into the bladder from which a duct, the urethra, carries it to the outside. Ovaries are small and eggs are very small. In many, the testes of the mature male occur in a sac outside the body. The red blood cells lose their nuclei before they are set free in the circulation. The Mammalia are divided into three sub-classes.

Sub-Class I — Prototheria, or Monotremata, are the simplest of Mammals. An example is Ornithorhyncus (Fig. 267), the duck-bill or duck-mole. The animal is about eighteen inches long. The head has a flat horizontal horny beak and the eyes are small. There is no external ear. The legs are short and the animal is 'squat-like' in appearance. The front feet are webbed and the tail is flat. Only the young have teeth, these being replaced by horny pads. The reproductive apparatus and habits are similar to those of reptiles and birds. Oviducts open into a cloaca, as do also the intestine and urinary apparatus. The eggs, which have a leathery shell, are incubated in shallow grass nests. The female has small *mammary glands* whose secretions are discharged among the overlying hairs of the abdomen. The young obtain nourishment at these places. The temperature of the body is lower than that of other Mammals and is more variable. The body is fur-covered. In many respects the Prototheria are the most primitive of Mammals. Ornithorhyncus is found in South Australia.

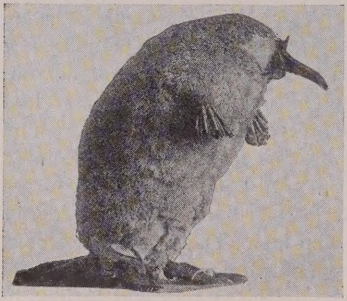

FIG. 267. — Ornithorhyncus — Duck-bill.

Sub-Class II — Metatheria. These are the opossums (Fig. 268) of America and the kangaroos (Fig. 269) and other less familiar forms, most of which occur in Australia. They are more commonly known as *Marsupials* for the reason that there is a pouch or marsupium on the ventral surface of the abdomen. In this pouch are nipples or teats containing ducts from the mammary or milk glands situated between the skin and the ventral muscular wall. Fertilization is internal since copulation takes place. The eggs are small with no shell or yolk and develop in the lower end of the oviduct (uterus) of the female. In only eight days, in case of Dasyurs; in two weeks, in the case of the opossum, and five weeks, in the case of the kangaroo, the young are "born." They are "foetus"-like in their immaturity but are carried around in the marsupium of the mother, where each is fastened to a teat and is fed upon the milk from the mammary gland. At first the milk is forced by maternal breast muscles into the foetus. The young develop in the marsupium for about eight weeks. The opossum may breed three times a year and each female may produce more than thirty young annually. It is a tree-dwelling form and is used as food. Most of the 39 living marsupial genera occur only in the Australian region. Evidences indicate that about the time of marsupial evolution and migration, the land connection between Australia and South America disappeared. The Marsupials left in Australia were confined to a restricted area. The Metatheria elsewhere were largely superseded by more dominant Eutherian Mammals since their evolution was favored by a larger range and more varied conditions. However, evolution of a sort took place among the Marsupials of Australia, for

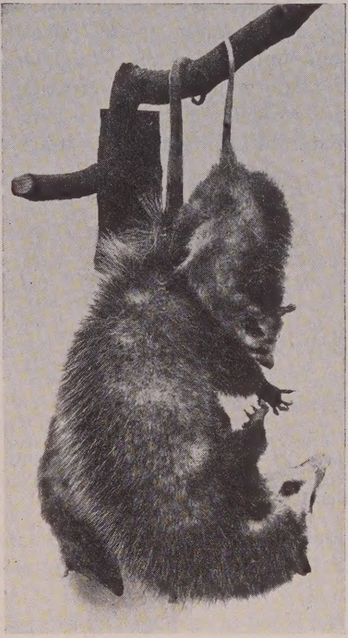

FIG. 268. — Didelphys virginiana. — Opossum. (Amer. Mus. Nat. Hist.)

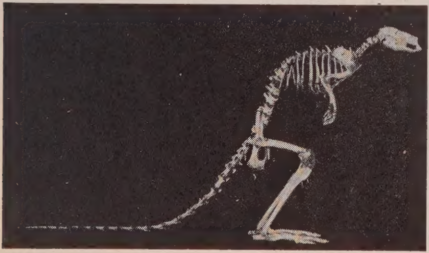

FIG. 269. — Skeleton of Kangaroo — Macropodus.

among them are found bear-like, wolf-like, rabbit-like, mole-like and mouse-like types.

Sub-Class III — Eutheria. The third sub-class of Mammalia are the *Eutheria* or *Real Beasts.* They are viviparous and are sometimes called the *Placentalia* or *Placental Mammals* because the embryonic form of nutrition is by means of a structure called the *placenta* (Fig. 270). This is partly embryonic and partly maternal in origin. It assumes various forms in different orders. It is formed against the inner wall of the uterus of the female. A long stalk, the *umbilical cord,* consisting of connective or supporting tissue and arteries and veins, connects the blood vascular system of the embryo to the placenta. Within the placenta is a system of large, thin-walled, expanded capillaries or sinuses. Some of these are connected with the circulatory system of the foetus. Others, dovetailing with the first, are connected with the circulatory system of the mother. The blood stream of the mother passes therefore in *close juxtaposition* to that of the foetus, but not directly into it. The blood of each system is separated from that of the other by a thin membrane. The red and white corpuscles and any foreign bodies, as, for example, Bacteria, that may possibly be present in the blood stream of the mother *do not pass* into the blood stream of the foetus. However, dissolved food and salt compounds, water, oxygen and probably vitamins and hormones present in the mother's blood do diffuse through into the foetal circulation. In the reverse direction, carbon dioxide and other wastes of metabolism diffuse from the foetal circulation back into the blood stream of the mother, who excretes them in addition to her own wastes. For the time being, the embryo or foetus is practically a parasite living at the expense of the mother.

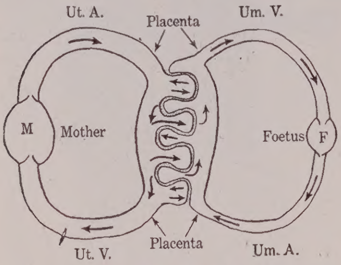

FIG. 270. — Scheme of foetal circulation. Ut. A. — uterine artery; Ut. V. Uterine vein; Um. A. Umbilical artery; Um. V. — Umbilical vein.

The offspring is helpless and dependent for a time after birth. Prenatal and postnatal care of the young reduce mortality during this period and are important factors in the dominance of the Mammalia. The eggs are very minute, containing very little reserve food. The posterior ends of the oviducts are fused, forming in Apes and Man the posterior single vagina and the more anterior single *uterus where the foetus develops* (Fig. 271). Because of the longer period of intra-uterine development, there is a reduction of the period of nutrition from the mammary glands as compared with the Marsupials.

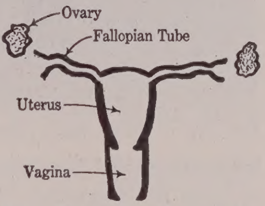

FIG. 271. — Female reproductive organs of man and apes.

The temperature of the body is higher than that of the two lower sub-classes and is more constant. It varies from 35° C. to 40° C. in different Mammals. The cerebral hemispheres become relatively larger and more convoluted among the higher groups. We find that these higher Mammals are adapted to live in diverse environmental conditions and that structural modifications accordingly occur. For example, the rabbit is a typical *terrestrial* mammal; horses and cattle are *cursorial* and adapted to swift running over the ground; dogs and cats are *terrestrial* forms, but not as completely *cursorial,* as they still use the limbs for other purposes; the sloth is adapted to life in trees, or *arboreal;* the mole to burrowing in the ground or *fossorial;* the porpoise to swimming life or *natatorial* and the bat is an *aerial* — or flying Mammal.

Orders of the Eutheria

Order I. Insectivora. These are regarded as the most primitive members of this sub-class. They are small Mammals with a pointed nose. Most of them feed on insects and worms. The body is covered with soft fur, as a rule. The moles (Fig. 272) (*Talpa*) are burrowing animals with the forefeet adapted for burrowing (fossorial) habits; no external ears and only rudimentary eyes are present.

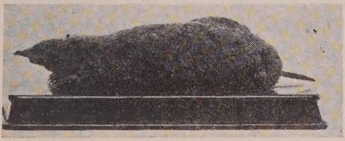

FIG. 272. — Talpa — Mole. (Amer. Mus. Nat. Hist.)

Order II. Chiroptera (Wing-like Hands). These are the bats (Fig. 273). The forelimbs are modified for flying. The bones of the forelimb and especially of the fingers are elongated. A fold of skin extends across them and alongside the body to the hind limb to form a flying organ. The thumb is short and clawed. The hind limbs are short and weak. Bats are active at night.

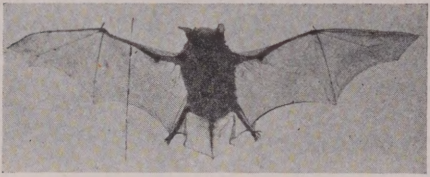

FIG. 273. — Brown Bat. (Amer. Mus. Nat. Hist.)

Order III. Sirenia (Fig. 274). An example is the sea-cow, an aquatic, sluggish, heavy-boned herbivorous Mammal. The hide is thick and possesses little hair. They have flipper-like forelimbs and no hind limbs. They live in rivers or near river-mouths. The Florida manatee is now very rare. It has been suggested that the idea of 'sirens' arose from sailor's yarns 'inspired' by seeing sea-cows.

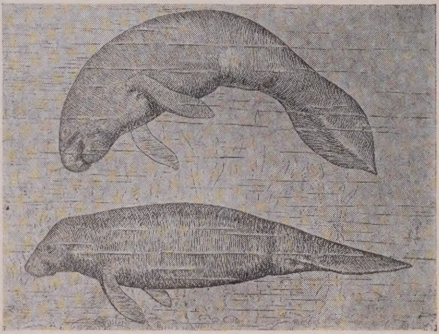

FIG. 274. — Manatus — Manatee. (U. S. Bureau Fisheries.)

Order IV. Cetacea. These are the whales (Fig. 275), porpoises and dolphins. They are truly aquatic and natatorial with fish-like bodies, and have lost the hair so characteristic of the Mammals. The forelimbs have become paddles, the hind limbs are gone, the tail is flattened horizontally into a *fluke.* There is usually a middle dorsal fin. A thick layer of fat or blubber under the skin aids in maintaining the high constant temperature, even in ice-cold waters. The body is torpedo-shaped. There are no external ears. The larynx is long and meets the internal nostrils so that there is a continuous passageway for air

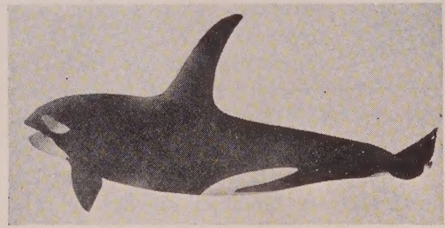

FIG. 275. — Killer whale — Orca. (Amer. Mus. Nat. Hist.)

from external nostrils to lungs. Cetacea do not breathe as often as other Mammals. In expiration, the animal *blows*. This leads to the wrong impression that in expiration these animals spout a column of water. All are *carnivorous*. Many of them live in groups.

One group of Cetaceans possesses teeth. These are the dolphins (*Delphinus delphis*), porpoises (*Phocaena communis*), killer whales and sperm whales. Sperm whales seventy-five feet long have been found.

True whales do not have teeth, but possess plates of baleen or whalebone which hang from the palate, filling the mouth like a sieve. They take in great quantities of water which passes through this whalebone sieve, retaining all small animals, which are used as food. The largest of all living animals, the sulphur-bottom whale, belongs to this group. It occurs in the Pacific Ocean. Some specimens taken were nearly 100 feet long and had a weight of nearly 150 tons.

Order V. Edentata. These animals have poor teeth or no teeth at all. The existing forms, found for the most part in South America, are but a few survivors of more numerous ancient types. Survival was insured by adaptive modifications in structure brought about by adoption of various modes of life. Some are *fossorial,* some are *arboreal* — some have their bodies covered with a strong protective armor. The Nine-banded Armadillo is found in Southern Texas. Anteaters are found in South America. Sloths (Fig. 276) also inhabit the forests of South America. They live almost entirely among the branches of trees and eat fruits, leaves and young buds. The front legs are longer than the hind legs, and the animals hang suspended from branches and crawl along this way, attaching themselves by means of the long, curved toe nails. The body is covered with long, shaggy hair. Edentates are thought to have originated in South America.

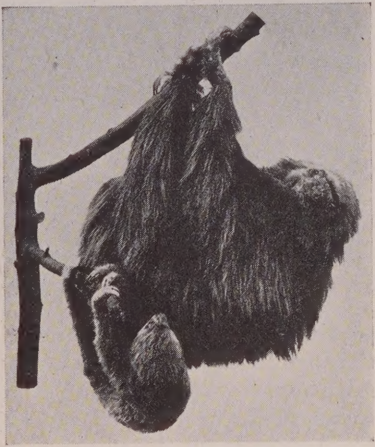

FIG. 276. — Two-toed sloth — Choloepus. (Amer. Mus. Nat. Hist.)

Order VI. Rodentia. These are gnawing animals — mice, rats, chipmunks, squirrels, rabbits, woodchucks, beavers (Fig. 277) and porcupines. The incisor teeth are long and chisel-like. With persistent use the teeth are kept sharp. They also grow continually. There are no canine or eye teeth. Most Rodents are small forms and most of them are terrestrial. There are more species of Rodents than of any other order of Mammals. Most of them are vegetarians. Carnivora feed largely on Rodents. Beavers live in the water. The hind feet are webbed, and there is a broad, flat tail which is used as a trowel in plastering mud in the construction of dams, which are made across a stream. Trees are gnawed and felled for this purpose. In the

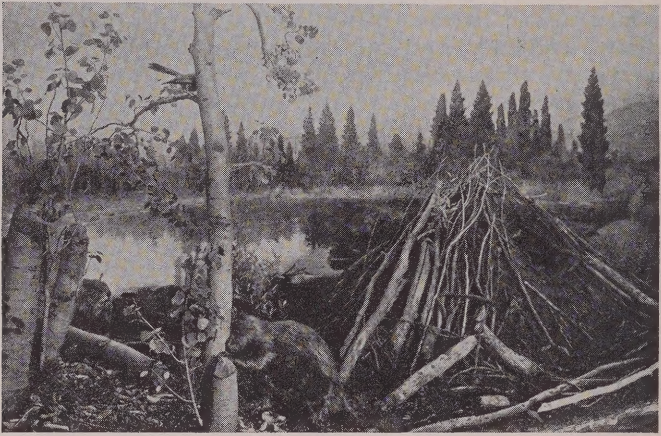

Fig. 277. — Colony of Beavers — Castor. (American Museum of Natural History.)

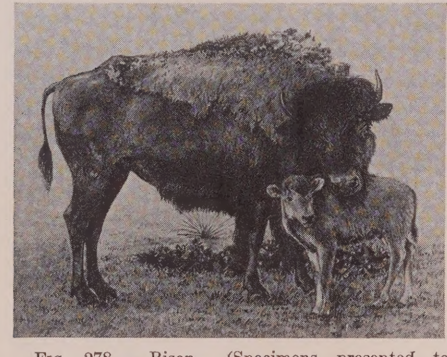

Fig. 278. — Bison. (Specimens presented to American Museum of Natural History by Buffalo Bill, W. F. Cody.)

pond thus made they build their nests or houses — the entrance being under water. It is a castle with a moat about it.

Order VII. Ungulata. These are hoofed animals and include a heterogeneous collection. They are *terrestrial, herbivorous* and use all the four limbs in locomotion. They do not walk on the soles of the feet as is usually the case, but upon the toes. The canine teeth are small or absent. The Ungulates are divided into several sub-orders.

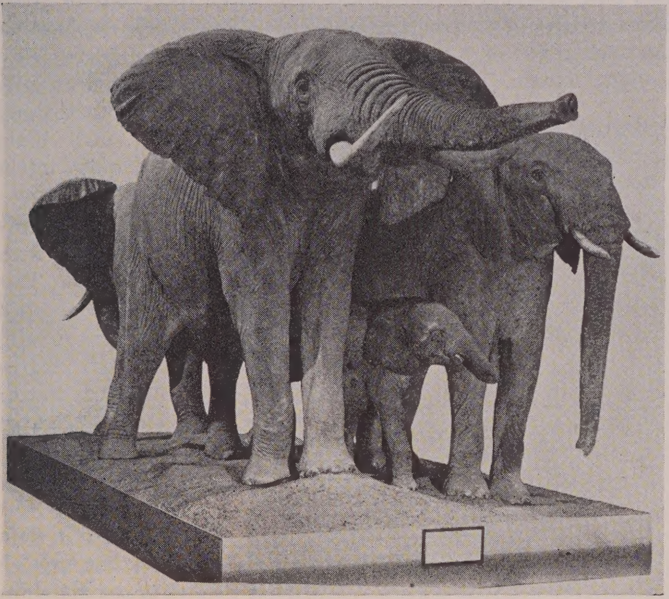

FIG. 279. — Elephas — African elephant. (Mounted by Carl Akeley at American Museum of Natural History.)

The *Artiodactyla* are cattle, pigs, peccaries, camels, hippopotami, giraffes, antelopes, sheep, goats, elk, moose, bison (Fig. 278), deer, etc. They are even-toed animals, the third and fourth toes being large and equally developed while the other toes do not develop. Millions of bison in great herds roamed the western plains of America about fifty years ago. Wholesale slaughter and the settlement of the country has caused their extinction as free, wild animals.

The *Perissodactyla* are horses, asses, zebras, tapirs and rhinoceroses. The middle or third toe of each foot is highly developed and used to bear the weight of the body. Rhinoceroses are large, fierce animals and also vegetarians.

The *Proboscidea* are the elephants (Fig. 279). The nose is prolonged into a proboscis or *trunk*, which is a tool with many uses. One pair of upper incisors form long tusks composed of ivory. There are five toes on each foot. When standing, the elephant has the appearance of a great mass supported at each corner by a straight column. Nevertheless the elephant can travel at great speed. Notwithstanding the small brain, they are quite intelligent.

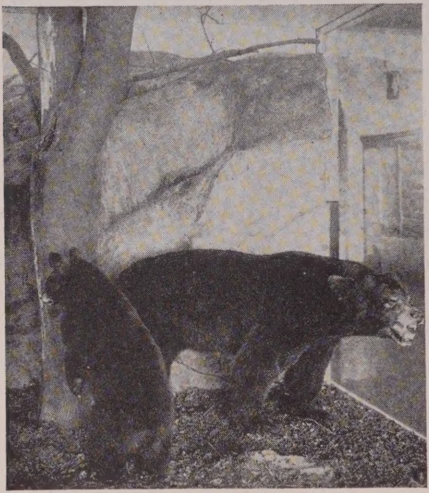

FIG. 280. — Black bears — Ursus. (Amer. Mus. Nat. Hist.)

Order VIII. Carnivora. These are flesh-eating animals. They are mostly ground-dwelling, coursing forms. There are usually four toes on each foot and the toes are supplied with claws. The limbs have other uses beside locomotion. They are used in striking down the prey, in fighting, and in holding the food while the animal tears it apart with its teeth or vice versa. The dentition is adapted to the type of food. Some are *omnivorous* and a few vegetarian. A prominent characteristic is the presence of long, pointed canine teeth whose uses are self-evident. Some of the teeth further back in the jaws (premolars) act on each other like scissors for cutting flesh. The stomach is simple and the intestine is short. They are fearless, aggressive, intelligent animals, keen of vision, hearing and smell, and their movements full of grace and beauty, oftentimes marred as *we* think by stealth and cunning.

They are divided into two great sub-orders. First, Fissipedia; second, Pinnipedia.

I. *Fissipedia.* The Fissipedia are mostly terrestrial forms. Among the familiar families are the (*a*) Felidae or cats, including the many varieties of domesticated house cats, the wild cat, tiger, lion, jaguar and leopard; (*b*) the Canidae or dogs, including the many varieties of domesticated dogs, the wolf, fox, jackal and coyote; (*c*) Ursidae or bears (Fig. 280), which are plantigrade, *i.e.*, they rest the entire sole of the foot on the ground in locomotion. Although they appear to be clumsy, yet they move with great agility, can strike powerful, well-directed blows and can travel at great speed.

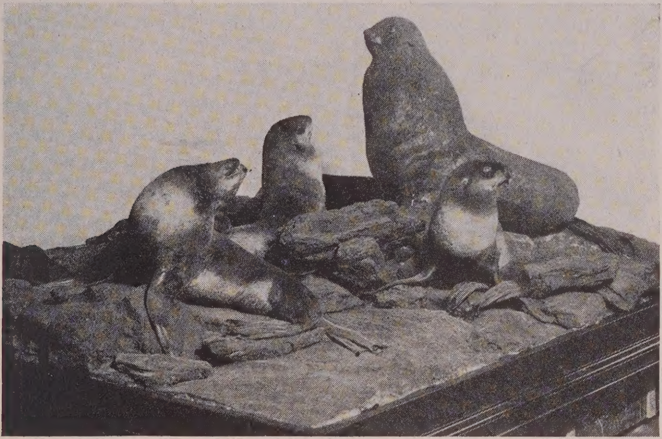

Fig. 281. — Fur seals. (Amer. Mus. Nat. Hist.)

II. *Pinnipedia.* This sub-order includes sea-lions, seals and walruses. The intestine of some forms attains great length, despite the fact that they are fish-eaters. The family, Otariidae, includes the sea-lions and fur seals (Fig. 281). *Otoes alascanus*, the fur seal, is polygamous, and a breeding male may have a 'harem' of many females. Males fight for this supremacy, the unsuccessful being called 'bachelors.' The breeding grounds are on the Pribilof Islands in Alaska. Most of the year is spent at sea. It is legal to kill three-year-old seals for their pelts. The regulations were formulated and are enforced by international treaty.

Order IX. Primates. We place this order at the end of the animal series because it includes man. However, morphologically, the Primates are not as specialized as the Ungulata and the Cetacea. The lower Primates do not superficially resemble man or the anthropoid apes, but because of certain characters they are included in the order. Most Primates live in warm countries. They are, on the whole, arboreal animals and tend toward the upright position, thus changing from a quadrupedal to bipedal habit. They will eat almost any form of food although many prefer fruit and insects. The limbs, and especially the hands, tend to be highly specialized, and the hind legs tend to be used for locomotion, thus freeing the front limbs for a variety of other uses. The brain is, as a rule, more highly developed than that of other orders. In most cases only one young is produced at birth and that receives parental care for a time after birth. Although some prefer a solitary life, yet most exhibit some sort of loose social grouping.

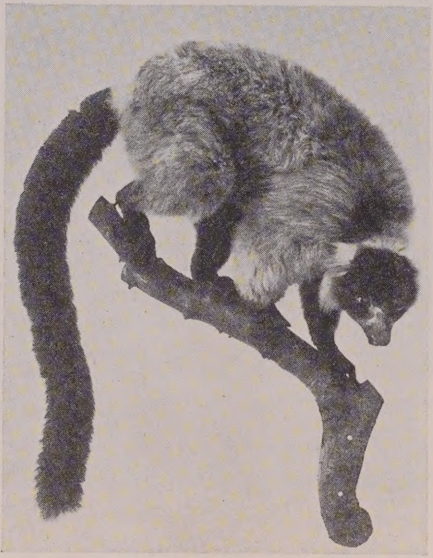

FIG. 282. — Varied Lemur — Madagascar. (Amer. Mus. Nat. Hist.)

Suborder 1. Lemuroidea. Family — *Lemuridae* (Fig. 282). These are the lowest. They are small, fur-covered quadrupeds with long tails. They are very abundant in Madagascar. Their faces resemble those of foxes, but their bodies are monkey-like. They link the Primates with the lower Mammals.

Suborder 2. Anthropoidea. Family — *Hapalidae* (Fig. 283). These are the small arboreal marmosets of Central and South America. The tail is long. They have prominent ears. The big toe has a *flat nail*, but the other digits have claws. The brain is relatively large and the nostrils are rather wide apart. Marmosets are often kept as pets.

Family — *Cebidae.* These are the South American monkeys, sometimes referred to as *New World monkeys.* They are small, active and arboreal. The tail is long and prehensile, the *thumb and big toe* are *opposable.* The *digits bear nails* and not claws. The nostrils are quite wide apart. The organ grinder's monkey belongs to this group. Howling monkeys are so-called on account of the frightful noises they make to scare away enemies.

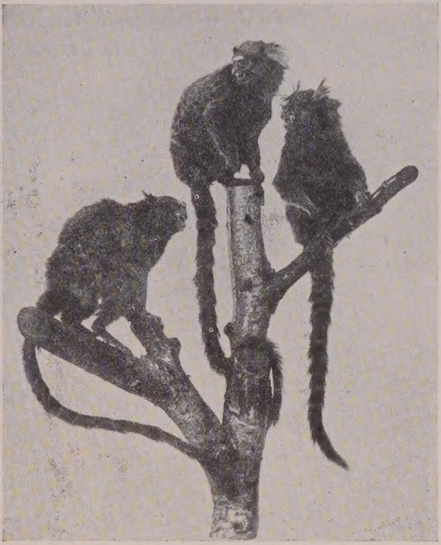

Fig. 283. — Marmosets. (Amer. Mus. Nat. Hist.)

Family — *Cercopithecidae.* These are the *Old World monkeys* found in Asia and Africa. They are quadrupeds with dog-like snouts but with the nostrils near each other. The tail is not prehensile but may be long. The macaques (Macacus) are common in all zoological collections. The male Mandrill (Papio) has brilliantly colored face and hips. The baboon (Cynocephalus) of Africa does not live in trees but among rocks.

Family — *Simiidae.* These are sometimes called *anthropoid* apes because of their resemblance to man. They include the gibbon, orang-utan, gorilla and chimpanzee. The breast bone is short and broad. Arms are longer than legs, there is no tail and they tend to walk with the feet turned in, a most convenient position in climbing trees.

The gibbon (*Hylobates*) is found in southeast Asia and the East Indies. They are mostly arboreal and omnivorous. They can walk erect. The orang-utans (*Simia*) (Fig. 284) are at home in Borneo and Sumatra in swampy regions. They assist themselves in walking by placing the knuckles on the ground. They live in nests in trees and are vegetarian.

The gorillas (*Gorilla*) (Fig. 285) live in equatorial Africa. They are the largest anthropoid apes and heavier than man although not as tall. They may weigh five hundred pounds and are powerful animals. They also use the knuckles when walking. They have been described as ferocious and at times are, although Carl Akeley states that this is not the usual mental state. Gorillas have been successfully ' tamed ' by Miss Cunningham of England, who found that the animals she dealt with showed evidences of considerable intelligence and affection.

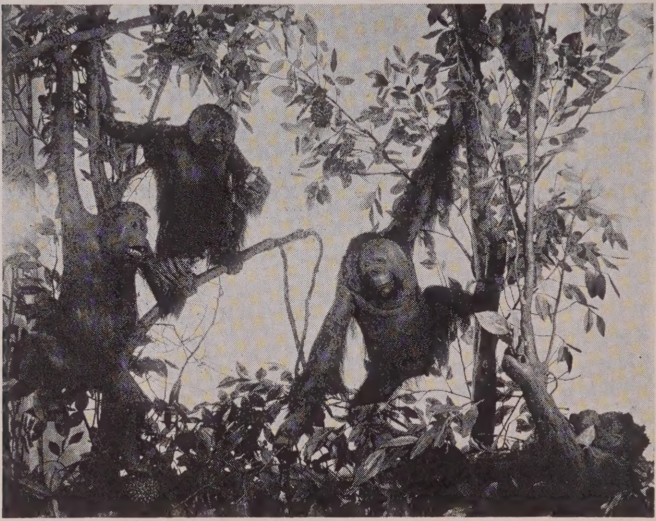

FIG. 284. — Orang-utans. (Amer. Mus. Nat. Hist.)

The chimpanzee, rightly named *Anthropithecus*, inhabits equatorial Africa. It lives in trees and among other things eats fruit. The chimpanzee has somewhat shorter arms than the gorilla and is not as large. It is more active and quite intelligent. They are easily tamed and are easily taught to dress, smoke, eat at table, ride a bicycle and *ape* man in a great variety of ways.

Family — *Hominidae.* This family contains but one genus and one species, *Homo sapiens.* Man differs anatomically from other Primates in the great development of the brain. The brain of the gibbon of all other animals is most like that of man in appearance but not in size. Man has an erect posture, is bipedal. The hind limbs are longer than his arms. In locomotion, the soles of the feet are flat on the ground, the great toe (hallux) is not opposable and his heel is better developed. With upright posture and head erect he has a greater view of his environment, the voice mechanism is better developed and language becomes a mighty instrument of power over nature. Social organization, of course, far surpasses anything of the sort found among other Primates.

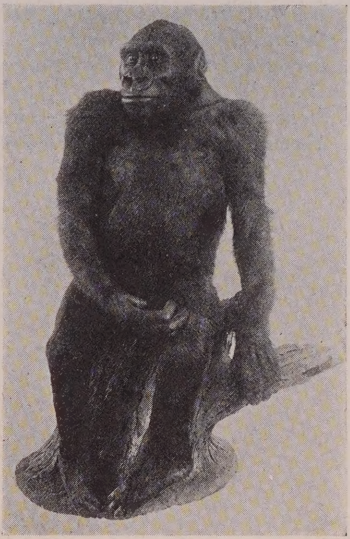

FIG. 285. — Gorilla — 'John Daniel.' (Amer. Mus. Nat. Hist.)

But his anatomy in many respects resembles the type pattern of the generalized Vertebrate, while some other forms are more specialized, as for example, the sulphur-bottom whale, which may weigh as much as a hundred ton ship, has *no hind legs* at all and its fore legs are comparatively small flippers, yet it is 'at home' in the vast expanse of the ocean. The human digestive tract is more generalized than that of the Ungulata. In limb plans, man is more like a frog than are the horse, cow and whale.

But it is brain, voice and hand that have become most specialized. The body has less hair than most Primates, the forehead more prominent, the face less extended, the canine teeth are small. The brain is used more than the teeth, in fact the use of the brain means less use for teeth and long jaws. The chimpanzee and man are anatomically more similar than the chimpanzee and monkey.

Although zoologists classify man as belonging to one species, one genus and one family, yet three races are *recognized,* namely, (*a*) the Negroid, (*b*) the Mongolian and (*c*) the Caucasian.

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PART III

GENERAL BIOLOGY

CHAPTER XVIII

THE CELL

PART I — MORPHOLOGY

Introduction. Living things are organizations of units called cells. Organs are composed of tissues which are composed of cells, which although of great variety of form yet exhibit evidences of a similar basic organization. All cells have many similar characteristics.

Some organisms consist of single cells or aggregations of similar cells, as, for example, the Protozoa and Protophyta. The gametophyte stage in plants begins life as a single cell, a spore. Metazoan animals and the sporophytes of plants begin life as a fertilized egg cell or zygote which develops into the adult organism. The word " cell " is a misnomer. Introduced first by Hooke in 1665, and applied by him to the microscopic box-like units forming cork tissue, the name has persisted, although today, and for nearly a century now, the word has connoted not an empty box but a small mass of living substance called protoplasm. In modern biological thought, *cell* and *protoplasm* are conceptions that should be thought of as merely two aspects of one phenomenon. In the present chapter, we shall consider the cell first from a morphological point of view.

Most cells possess many similar structures. In the center of the cell can be seen a small body, circular in outline and lighter in color. This is the nucleus; the portion outside the nucleus is the cytosome, and both are composed of protoplasm. The nucleus is visible in many living cells. Both cytosome and nucleus are optically so homogeneous that few details are revealed by a study of the living cell. But cytological technic enables us to extend our knowledge of these regions (Fig. 286).

Cytosome. The protoplasm constituting the cytosome is called cytoplasm. This is a translucent, somewhat jelly-like substance. Max Schultze described it as being a viscid fluid, *hyaloplasm,* containing microscopic granules called *microsomes.* Later workers studied its appearance after treatment with killing and fixing reagents, and Leydig, for example, stated that the hyaloplasm supported a fine network of fibrils which he called *spongioplasm.* Later, Bütschli in 1890 studied living protoplasm of Protozoa and described it as being composed of very small, different-sized globules, distributed in a liquid medium, the hyaloplasm of Schultze. Bütschli called the globules, *alveoli*, and his conception is known as the *alveolar theory.* According to this theory, protoplasm resembles an emulsion. It is pretty well agreed now that cytoplasm consists of viscous clear fluid — *hyaloplasm* — permeated in some cases by *granules* of different sizes, in other cases by *fibrils,* sometimes very fine, sometimes coarser, as in nerve fibers; and in still other cases by different sized globules or *alveoli.* In the interalveolar substance granules or *microsomes* are at times observed. Certain studies reveal evidence of granules changing to alveoli, or the reverse in certain cell activities. The granule is possibly an early stage in the formation of the alveolus.

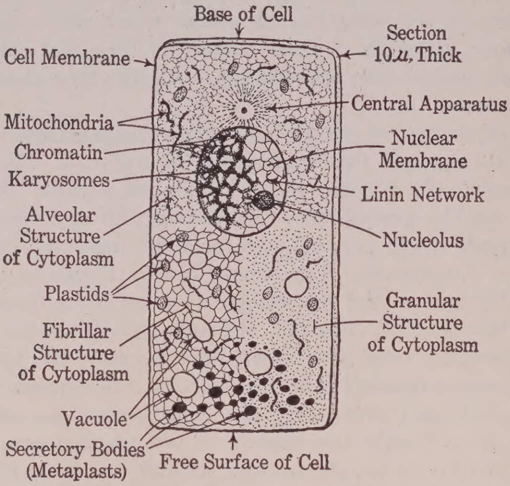

Base of Cell
Section 10μ Thick
Cell Membrane
Central Apparatus
Mitochondria
Nuclear Membrane
Chromatin
Karyosomes
Linin Network
Alveolar Structure of Cytoplasm
Nucleolus
Plastids
Granular Structure of Cytoplasm
Fibrillar Structure of Cytoplasm
Vacuole
Secretory Bodies (Metaplasts)
Free Surface of Cell

FIG. 286. — Diagram of a section of a cell illustrating general morphology of cells.

Special staining fibers called *mitochondria* have been found in most kinds of cells. These appear to be linear groupings of granules. They seem to be scattered granules in embryonic cells and a thread-like arrangement of granules, *i.e.*, fibrils in older differentiated cells. Their function is still problematical. They are regarded as permanent morphological structures of the cytosome. Some workers believe that they form the myofibrils of voluntary muscle fibers, and the neurofibrils of a nerve fiber; others state that they play an important part in inheritance and still others assign other functions to them. In the cytosome, at times, are found *chromidia*, which are masses of chromatin discharged from the nucleus.

In some cells, chiefly those of plants, are found special bodies called *plastids*. In the mesophyll of the leaf occur green *chloroplastids*, living, self-propagating bodies containing chlorophyll and therefore vital to the formation of starch. Non-living bodies or substances called *metaplasts* occur in cytoplasm. These are products of the cell's activity. A gland cell forms granules which are discharged from the cell in a liquid form called a secretion. Parenchyma cells in plants contain starch grains. Cells, chiefly those of Protozoans and of plants, contain spaces called *vacuoles*. The contractile vacuoles of Amoeba and Paramecium are intracellular organs which, beginning as minute structures, increase in size, contract and repeat the same changes rhythmically. They are probably drainage reservoirs for liquid wastes of excretions which are discharged by contraction. The *fat cell* of animal adipose tissue is a large vacuole or droplet of oil surrounded by a thin pellicle of cytoplasm at one point of which is the nucleus of what was once a small stellate connective tissue cell. The vacuolated condition of plant cells is characteristic of them. The plant cell is inclosed in a box of cellulose, and the inner surface of this is lined with a thin layer of cytoplasm at one point of which may be the nucleus. Strands of protoplasm may form a crude network within the cellulose walls and the vacuolated spaces within this network are filled with cell sap.

Nucleus. The nucleus is such a characteristic structure that Schultze defined a cell as a mass of protoplasm containing a nucleus. It is now known that nuclear matter is protoplasm, differing somewhat chemically from that of the cytosome. The nucleus of plant cells was discovered in 1831 by Robert Brown, an Englishman, described by Humboldt as the "most famous of botanists." As a rule there is but one nucleus. No distinct nucleus can be demonstrated in Bacteria although staining methods indicate distributed nuclear material. Distinct nuclei are not seen in the cells of Blue-green Algae. Red blood cells of Mammals lose their nuclei after they are formed, and yet these cells remain functional. They later disintegrate without dividing. Certain Protozoa have a long beaded nucleus. Although most of the cells of the liver are uninucleated, some are found with two nuclei, and the giant cells of developing bone have many nuclei. In a certain type of white blood cell the nucleus may be in the form of irregular masses connected by small strands. The nucleus is inclosed in a nuclear membrane which disappears during cell division. The protoplasm of the nucleus consists of a liquid nucleoplasm or nuclear sap traversed by a network of *linin fibers.* Neither of these stains well with basic dyes such as haemotoxylin, and hence are called the achromatic parts of the nucleus. The colorless linin fibers support fine granules called *chromioles.* Where the fibers cross each other, little masses of chromioles are present, forming *karyosomes.* During cell division the chromioles fuse to form distinct aggregations or bodies called *chromosomes.* Chromosome substance has a great affinity for (basic) dyes, such as hematoxylin. On account of its staining property, this unique cell substance has received the name *chromatin.* Chromatin is a nucleo-protein compound containing nucleic acid. The intensity of staining with basic dyes depends on the proportion of nucleic acid present. Most nuclei possess a small body called the *nucleolus,* which is spherical in form and dense in appearance. It is not a chromatin body because it stains with acid or neutral dyes. Some cells have no nucleoli. The function of the nucleolus is not understood.

It is believed that the nucleus regulates the metabolic activity of the cells. An enucleated mass of cytoplasm may continue to function for a short time, but soon dies, for metabolic processes connected with feeding cannot take place. Such a piece continues to live until the supply of energy available is dissipated. A piece of cytoplasm containing a nucleus or part of a nucleus of adequate size does continue to function and will regenerate a new cell. Certain observations lead to the interpretation that the nucleus is directly concerned with secretory activities. It is pretty well agreed that there is a constant interaction between nucleus and cytosome. The organization termed the cell, therefore, has at least two different regional organizations *within it,* namely, that of the cytosome and that of the nucleus.

If one body cell of an organism contains a certain number of chromosomes, then every body cell contains a similar number and the body cells of any other animal or plant of that same species contains the same number of chromosomes. Chromosomes or chromioles are now thought to contain ultramicroscopic multimolecular masses of protein substance called *genes* which are the determiners of inherited characteristics, but function only in germ cells. That is, although the chromosomes of a liver or muscle cell, for example, are similar in this respect to those of a germ cell, yet the heredity function is inhibited in all cells except mature sex cells.

Centrosome. Near the nucleus, at the time of cell division, a small body called the *centrosome* appears in most animal cells, but rarely in plant cells. The centrosome is surrounded by a clear area of cytoplasm known as the *centrosphere.* From this clear area extend radiating protoplasmic strands, or spindle fibers, in all directions, thus constituting the *astrosphere.* The centrosome or centriole, the centrosphere and the astrosphere constitute the *central apparatus.* It is described as the dynamic center which organizes the apparatus, or mechanism, engaged in cell division.

Cell Membrane. At the surface of liquids where they are in contact with air, a film is present, possessing the property known as surface tension. The existence of this film can be demonstrated by rubbing a needle with a little oil and laying it carefully on the surface of the water in a dish. The needle floats. If the film is broken, the needle sinks. The properties of the film depend on the nature of the medium of which it is the boundary. Cytoplasm is a semifluid substance. As such, the boundary of the cell is a surface membrane or film, probably possessing an aggregation of particles more dense than the rest of the cytoplasm. It appears to be rich in proteins and phosphatides. The cell membrane regulates the passage of oxygen and food compounds into the cytoplasm and also carbon dioxide and nitrogenous waste products out of the cytoplasm. Through it must pass also secretory products that perform useful work elsewhere. The exposed surface of some cells, as those forming the outer part of the ' skin ' of the earthworm, have a thickened, tough external wall called a cuticle. The cytoplasm of plant cells (Fig. 287) secretes a box-like cellulose wall outside the real cell membrane. Not all cells have cell membranes. The histologic unit of voluntary muscle tissue is

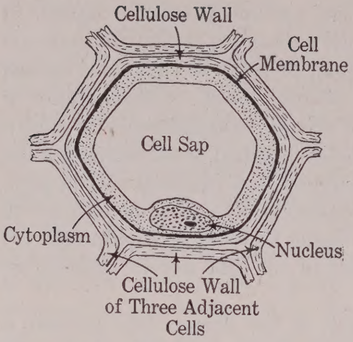


FIG. 287. — Diagram of a plant cell. From Sinnott, *Botany*, 2nd edition, McGraw-Hill Book Co. Reprinted by permission.

a cylindrical multi-nucleated mass of protoplasm. The protoplasm of one nuclear region is not separated by a membrane from the protoplasm of adjacent nuclear regions. Nevertheless, it is proper to call such a grouping a mass of cells. In such a case, the special arrangement in which cells are not separated from each other by a cell membrane is called a *syncytium*.

Shape of Cells (Fig. 288). Cells vary greatly in shape. In many cases single free cells are spherical — for the same physical reasons that determine the contour of a drop of water or jelly. The egg cells of many animals are little spheres. Some soft-walled cells in masses are irregularly polygonal in form with flattened sides much like the form of bubbles in a mass. The parenchyma tissue of plants is composed of cells of this form.

Some cells resemble bricks set on end and arranged side by side, as columnar epithelium, for example. Cells belonging to this general type are shaped like short columns or cubes. The epithelium that forms the walls of capillaries

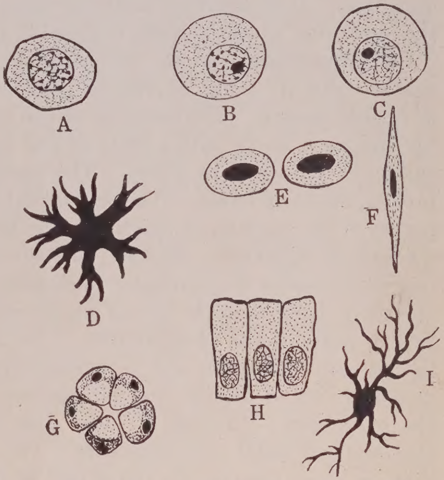


FIG. 288. — Variation in shape of cells. *A*, human egg cell; *B*, egg cell of cat; *C*, egg cell of sea-urchin; *D*, pigment cell from skin of frog; *E*, red blood cells of frog; *F*, smooth muscle cell; *G*, five pancreas cells; *H*, columnar shaped cells from intestine; *I*, nerve cell from brain.

consists of flat, thin cells with irregular outlines. The smooth muscle cell is long and spindle-shaped. One type of nerve cell has a stellate body with a long, attenuated process extending from the nucleated body part. We have already noted great variation in the form of Protozoa and Protophyta.

Size of Cells. For the most part cells are microscopic in size. Some single-celled animals can just be seen with the naked eye, and look like tiny white specks. However, most cells are very much smaller. 0.001 millimeter equals one *micron*, represented by the letter "μ." It has been claimed that most of our own cells are 5 μ in diameter. Yeast cells are about 7 μ in diameter. Human red blood cells are circular discs about 7 μ in diameter. The human egg cell is about 135 μ in diameter, while the human sperm cell is 50 μ long. Bacteriologists believe that there are Bacteria so small that they cannot be seen with the microscope. Animals of different sizes have cells which are of about the same size; as, for example, the elephant and the mouse. The hen's egg is a single large cell, yet the shell and the white are not part of the cell, but merely associated with it. The egg cell nucleus and protoplasm is a tiny microscopical mass on the top of the yolk. The ostrich egg is still larger, but this is because there is so much more yolk present. The egg of the elephant, on the other hand, is microscopic in size. The human body contains millions of cells. It is a community containing more members than the population of the earth, and in health these units function as a perfect whole.

History of Ideas Concerning Cells. In the seventeenth century the compound microscope had come into use. An Englishman, Robert Hooke, examined many objects with this new and fascinating instrument. He cut cork into thin slices and studied them. He noted that cork was an assemblage of little box-like units, which he called *cells.* Contemporaries of his in other countries also studied thin preparations of plant tissues microscopically, and even drew diagrams of somewhat similar "cells," but overlooked their importance. In 1759 a German embryologist, Wolff, saw little "globules" in early embryos. Yet Bichât, the founder of histology (1771–1802), in spite of all his microscopical investigations, did not discuss cells. Oken, a somewhat fanciful philosopher, in 1805 stated that he could easily prove "that animals and plants were nothing but numerous aggregations of vesicles," but his mere statement carried no conviction. During the later years of the eighteenth century the idea was developing that animals and plants were, after all, composed of "globules."

During the early years of the nineteenth century the *cell* was more and more discussed in scientific papers, especially those dealing with plant structures. In 1831, Robert Brown ascertained that within each was an inner body, the nucleus. At this time in Germany, a botanist, Schleiden (Fig. 289 *A*), concluded that to understand plant structures it was necessary to know their development. Brown's discovery of the nucleus suggested to Schleiden that new cells originated from this. He worked along this line. Incidentally his ideas as to the development of new plant cells were erroneous. It was in 1838 that he happened to tell Theodore Schwann (Fig. 289 *B*) about his work. As a result Schwann exhibited some of his own preparations of animal tissues to Schleiden, who saw in them nuclei which resembled those of plant cells. Schwann was led to conclude that the units of animal tissues were very similar to those of plants.

Fig. 289 *A*. — Schleiden. From Locy, *Biology and Its Makers*. Courtesy Henry Holt & Co.

Although usually credited with being one of the founders of the *Cell Theory*, Locy considers that Schleiden's chief service consisted in suggesting the idea to Schwann, who further developed it, publishing a brief account of his views in 1838, and in 1839 a long and carefully planned and illustrated monograph. The title of this classic was "Microscopical Investigations on the Correspondence in Structure and Growth of Animals and Plants."

He said that the investigation indicated the identity of structure of plants and animals, as shown by their development, and concluded that "the elementary parts of all tissues are formed of cells in an

Fig. 289 *B*. — Schwann. From Locy, *Biology and Its Makers*. Courtesy of Henry Holt & Co.

analogous though very diversified manner." "The development of the proposition that there exists one general principle for the formation of all organic productions and that this principle is the formation of cells, as well as the conclusions which may be drawn from this proposition, may be comprised under the term, Cell Theory." Schwann was in many respects wrong in his understanding of the structure and development of cells, but he did succeed in establishing the idea of the cellular nature of plants and animals so that a great amount of critical work on the detailed structure of cells followed. It should be said here that although Schwann was led to his conclusions regarding the cellular nature of all organisms by a study of the nervous system, yet it was not until the latter part of the nineteenth century that it was finally accepted so that even the nervous system was included in the general law. The special application of this to the nervous system is known as the "*Neuron Theory*" — a neuron being a special name for a nerve cell.

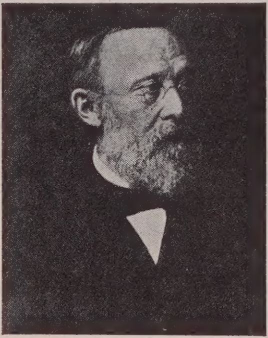


FIG. 290 *A.* — Virchow. From Locy, *Biology and Its Makers*, Courtesy of Henry Holt & Co.

It gradually became evident that the cell was the locus of physiological activities, and the physiology of an organ was to be explained by finding out the physiology of its cells. The importance of the cell in embryology was recognized and that science advanced greatly. The greater importance of the cell in heredity was made clear, and much work along this line is continuing at present. In 1861, when Schultze made his great generalization, he emphasized the fact that cells are masses of protoplasm, each containing a special mass of protoplasm — the nucleus. In 1855 it was accepted that new cells could arise only from preceding cells. Cells would not arise *de novo*. Virchow (Fig. 290 *A*) introduced a now famous phrase, "*Omnis cellula a cellula.*" Wilson says with regard to the Cell Theory that "No other biological generalization save only the theory of organic evolution has accomplished more for the unification of knowledge."

Aspects of the Cell Doctrine. Thomson says "that the cell doctrine has three aspects: (1) Morphological, *i.e.*, that all plants and animals are composed of cells; (2) Embryological, *i.e.*, every organism begins life as a single cell; (3) Physiological, *i.e.*, the functions of higher organisms are expressible in terms of the activities of their cells." "Each cell," said Schleiden in 1838, "leads a double life, one pertaining to its own development, which is independent, and a second as an integral part of plant or animal." Schwann expressed this idea in these words, "The whole organism subsists only by means of the reciprocal action of the single elementary parts." Virchow, in 1859, said, "Every animal appears as the sum of vital units, each one of which bears with it the characteristics of life." Thomson has put it thus, "These conclusions combine in impressing us with the unity of organic nature, for although a plant cell is often very different from an animal cell, and one animal or vegetable cell may be very different from another in the same or another body, yet the points of agreement in structure, in development and in function are at least as striking as the observable differences, and often more striking."

Vitalism and Mechanism. Protoplasm or cell substance is not merely a mixture of complex materials. Brucke, in 1861, stated, "We must ascribe to living cells, in addition to the molecular structure of organic compounds which they contain, still another and otherwise complicated structure (property or characteristic); and this is what we designate by the term organization." Inseparably connected with the physical and chemical structure of protoplasm is the functioning of protoplasm. Inseparably connected with the societies of cells must be an integrative activity of whole mass as a unit. This organization cannot be dissected; it cannot be seen with the aid of a microscope. It is not material in the ordinary sense of the word. This has led to the development of two general ideas or schools of thought — *Vitalism and Mechanism.* The vitalist says that life is *more* than mere physical and chemical reactions, as claimed by the mechanist, and that we have not yet been able to elucidate what life is. Many mechanists, on the other hand, have a tendency to present explanations of life processes in terms far too simple to unknown complexities. One result, however, of the vitalistic idea is to stifle investigation. The mechanistic position has done more to stimulate research, and many valuable discoveries have, as a consequence, been made.

The truth of the matter probably lies in the *direction* of mechanism. Investigators in physics and chemistry know very well that all the knowledge they possess *today* concerning matter and force is incomplete. Nature is still, to a great extent, *unknown* to them, but they are making new discoveries constantly. The biological mechanist, who confidently asserts that life processes are merely exhibitions of phenomena taking place according to known laws of physics and chemistry, is open to criticism fully as much as the vitalist. The salvation of the mechanist is that he keeps busily at work. When the mechanist arrives at a barrier, he changes the method of attack. Some idea of the nature of chemical and physical explorations in the field of cell physiology is presented in the following section,

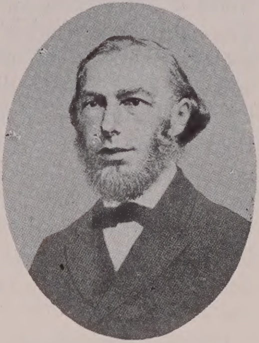


FIG. 290 *B.* — Schultze. From Locy, *Biology and Its Makers.* Courtesy of Henry Holt & Co.

PART II — CHEMISTRY AND PHYSICS OF PROTOPLASM

Introduction. Cells are morphological units. They are also protoplasmic organizations of complex compounds in which actions and reactions occur and recur during life. Prior to 1828 it was customary to regard matter as occurring in two forms — inorganic and organic. In the year just referred to, Wöhler was able to *make* urea, a characteristic organic compound. He synthesized it from inorganic compounds. This experiment broke down the barrier separating organic from inorganic chemistry and indicated the chemical relationship of all existing substances. About 1860 Schultze (Fig. 290 *B*) came to the conclusion that the living matter of plants and animals was essentially similar. He arrived at this conclusion from a study of the *appearance* of this substance. An eminent English zoologist, Professor T. H. Huxley (Fig. 290 *C*), in an address in Edinburgh in 1868, referred to protoplasm as the "Physical Basis of Life."

FIG. 290 *C.* — T. H. Huxley.

The chemist has determined that the inorganic world, *i.e.*, lifeless matter, consists of compounds of some ninety chemical elements. Chemical examination of protoplasm reveals the fact that it is composed of a *certain few* of these elements. The living world is but a *phase* of the great world of matter and energy. The astronomer studies the turbulent 'flames' of the sun; the geologist notes continental elevations, the erosion of mountain valleys; the biologist, the germination of a seed, the busy activity of a honey bee or the division of a cell. All are manifestations of matter in motion. The laws of conservation of matter and of energy apply to the whole knowable universe. Moreover, there is no complete discontinuity in the numberless transformations of matter from the simple to the very complex, from the inorganic to the organic, or from the most complicated compounds of protoplasm back to the elements found in it. It is all *one* world.

Physical Appearance. In the description of the morphology of the cell, attention was called to the physical appearance of cell substance — protoplasm. To this may be added that it is translucent and nearly colorless, sticky, viscous, cohesive, heavier than water; jelly-like in some cases, more fluid-like in others.

Chemical Elements in Protoplasm

Chemical analysis reveals the following elements occurring in protoplasm: Carbon, Hydrogen, Oxygen, Nitrogen, Sulphur, Phosphorus, Sodium, Calcium, Potassium, Magnesium, Chlorine, Iron, Manganese, Iodine, Silicon, Copper and at times traces of others. A study of each of these reveals interesting facts.

Carbon. The greater part of protoplasm by weight is carbon. The primary materials of protoplasm are carbon compounds. They are combustible, they unite with oxygen to form carbon dioxide and water and at the same time liberate energy. In the inorganic world carbon combined with oxygen produces carbon dioxide and liberates energy. Carbon dioxide of the atmosphere is utilized by plants in the reorganization of oxidizable carbon compounds.

Hydrogen exists as part of water and other compounds of protoplasm. Hydrogen ions are constantly liberated in protoplasmic activities and tend to effect an acid condition which is as constantly neutralized. The presence of hydrogen ions affects greatly many of the chemical reactions characteristic of living things. In fact, evidences indicate that the transfer of energy in biological oxidations is mediated by hydrogen transfer.

Oxygen has a unique place among all the protoplasmic elements. Oxidation reduction is one of the commonest features of protoplasmic activity; it releases the energy for life processes.

Nitrogen is absolutely essential to protoplasmic formation. It forms 79 per cent of the atmosphere, but is not available to any great extent to the living world. The transfer from the non-living to the living world is by way of nitrates taken from soil water by roots of plants.

The above-named elements are ‘ the big four ’ of protoplasmic compounds. But since elements occur in definite chemical compounds, quite characteristic of protoplasm, it is more instructive to study these.

The physiologist, Verworn, advanced the theory that protoplasm was one exceedingly complex but unstable chemical compound of all or most of the above-named elements. He called this gigantic molecule a *biogen*. Sir Michael Foster, however, expressed the prevailing view when he described it as a mixture of molecules, between which temporary combinations or associations are constantly taking place, and as constantly parting company to combine elsewhere and otherwise. “ It is a complex whirl, an intricate dance of composition — the renewal of the protoplasm is but the continuance of the dance, its functions and actions the transfer of figures,” — *i.e.*, analogous to a dance in which different groupings are made and broken.

The Compounds in Protoplasm

These are (1) water, (2) salts and inorganic elements, (3) proteins, (4) carbohydrates, (5) lipoids and fats, (6) enzymes, (7) hormones, (8) vitamins, (9) gases.

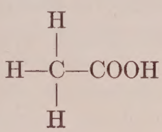
Water. Life probably arose in an aqueous medium. About 70% of protoplasm is water. Mammalian muscle contains about 75%, bone 25% and the jellyfish has been described as animated seawater. Water is the medium in which protoplasmic transformations take place. Extreme dehydration or loss of water usually means death. The other compounds of protoplasm are dissolved in it. Transportation of material to and from the cells of metazoans occurs in aqueous solutions. Solutions carry electrical currents; aid in speeding up chemical reactions; have high specific heat and so absorb and dissipate the heat of chemical reactions that might injure the cell. Dissociation of compounds easily occurs in them. We shall presently describe many physico-chemical processes, necessary to life, that occur in a water medium.

Inorganic Salts. These are usually chlorides, sulfates, carbonates and phosphates of calcium, sodium, potassium and magnesium. The salt solutions of protoplasm resemble those of the sea. They do not occur in the same amounts as in sea water, but the proportions present suggest that the sea water is similar to the salt solutions of living matter. Matthews says, "It has been suggested that it was in some slowly drying volcanic pool, that living matter first appeared." "We are the children of the sun and the sea." Salts enter into combination with compounds presently to be described. They play an active part in the chemistry and physics of the living process.

Proteins. Proteins are complex compounds of carbon, hydrogen, oxygen, and nitrogen, and in some cases also phosphorus and sulphur. They constitute the greater part of protoplasm after dehydration. They are combinations of peculiar elementary compounds known as amino-acids. An amino-acid has been described as containing a central carbon atom with four valences and associated — *first*, with a hydrogen atom; *second*, with a carboxyl group, COOH; *third*, another hydrogen atom; *fourth*, an amino group, NH_2. The latter suggests a relation to ammonia, an inorganic compound. Ammonia is one of the disintegration products of proteins, accomplished by decay Bacteria. Ammonia solutions in the soil are eventually changed by Bacteria to nitrates which are absorbed by plant roots and made into amino-acids and proteins by plant cells.

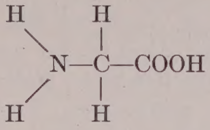
The initial organization of amino-acids and proteins is accomplished chiefly by plants, although animals possess this power to a limited degree. Animals secure their proteins almost entirely from their plant food.

The formula for acetic acid is CH_3COOH. This may be pictured as follows:

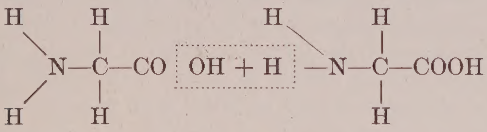


$$\begin{matrix} & \mathrm{H} & \\ & | & \\ \mathrm{H}- & \mathrm{C} & -\mathrm{COOH} \\ & | & \\ & \mathrm{H} & \end{matrix}$$

By substituting an NH_2 group for one of the H atoms, the result is:



This can be written $NH_2 \cdot CH_2 \cdot COOH$. But this is one of the eighteen or twenty known amino-acids. It is called *glycocoll* or *glycine.* Amino-acids combine to form more complicated compounds called proteins. As depicted in the formula for glycine, an NH_2 group is shown at one side of the carbon atom and opposite it, a carboxyl group, COOH. When amino-acids combine, there is a tendency for an OH part of the carboxyl group of one acid to unite with one of the H atoms of the amino group of another acid to form water, and also for the two acids to combine at that point. In other words, it is a linkage between the carboxyl group of one acid with the amino group of another. A simple illustration of this is shown below; two glycocoll molecules take part in the reaction:



The dotted rectangle shows what takes place. The resulting compound may be written thus: $NH_2 \cdot CH_2 \cdot CO \cdot NH \cdot CH_2 \cdot COOH + H_2O$. This very simple amino-acid may be called *glycine-glycine.* The formula of *alanine*, another amino-acid, is $NH_2 \cdot CH_3 \cdot CH \cdot COOH$; and the formula of *valine* is $CH_3 \cdot CH_3 \cdot CH \cdot CH \cdot NH_2 \cdot COOH$. The amino-acids *known* to play a part in the formation of most proteins occurring in living things are: 1. Glycine; 2. Alanine; 3. Valine; 4. Leucine; 5. Isoleucine; 6. Caprine; 7. Phenylalanine; 8. Tyrosine; 9. Serine; 10. Cystine; 11. Aspartic acid; 12. Glutamic acid; 13. Arginine; 14. Lysine; 15. Histidine; 16. Proline; 17. Oxyproline; 18. Tryptophane. They have been isolated from proteins. Animals feed on highly organized proteins. Enzymes in the digestive tract disintegrate these into simpler compounds, probably amino-acids, which pass into the circulation and thus reach the cells of the various tissues. Within the cell the amino-acids are reorganized into the proteins of that cell. There are *many* kinds of proteins. For example, about one fifth of muscle substance is the protein, myosin; and about ten per cent of the white of egg is egg albumen; casein occurs in milk; gluten in wheat flour; legumen in peas and beans; zein in corn. Proteins have great molecular weight. For example, the molecular weight of egg albumen has been estimated to be 33,800; of gelatin, 123,000; of casein to be 192,000. The molecule is extremely complex. This is faintly indicated by the formula for hemoglobin, said to be $C_{758}H_{1203}N_{195}S_3FeO_{218}$. Amino-acids may combine with acids or bases. Glycocoll combines with hydrochloric acid to form glycocoll hydrochloride or with potassium to form potassium glycocollate. This property is of great moment in vital activities. Some proteins lack certain amino-acids, few contain all. If the food of an animal lacks just one amino-acid which normally takes part in the organization of that animal's protoplasm, then that food is deficient. Ordinary diet is so diverse that it probably contains all the amino-acids *we* need. In times of famine, when food variety is greatly restricted, the deficiency in necessary amino-acids may be as serious as the lack in quantity of food.

The protoplasm of the tissues of different animals, although in many respects similar, differs in details. One might think that the blood of Mammals is quite identical in all respects. This is not true, for even a small amount of blood (5 cc.), of one animal introduced into the blood stream of another species of animal acts as a poison to the recipient. Biochemists conclude that there is a vast number of different protein compounds in animals and plants. The possible permutations and combinations of the amino-acids are beyond human comprehension. Proteins are used chiefly for the reconstruction of protoplasm destroyed in cell activity. During the development of an organism, additional protoplasm is needed for the increase in cell population, for the tissues and organs so that an intense production of proteins occurs then.

The presence of NH_2 groups tends toward a basic condition while the COOH group tends toward the acid condition. In living matter there is a constant slight transition back and forth between the slightly acid and the alkaline condition with a tendency toward the slightly alkaline. The peculiar structure of the amino-acids is adapted to the characteristic chemistry of the living process.

Only plants can construct amino-acids and so eventually proteins from inorganic compounds. Animals are dependent upon plants. Plant proteins are made over into the peculiar protein of the particular kind of animal feeding on these plants.

Carbohydrates. These are compounds of carbon, hydrogen and oxygen, in which the last two occur in the same proportions as in water. One of the great basic operations of plant life is the manufacture of carbohydrates from carbon dioxide and water. There are many combinations of the carbohydrates. Three of these will be discussed. The formula of one group is $C_6H_{12}O_6$. But different arrangements of atoms in such a molecule are possible and so there are a number of different compounds having the molecular formula, $C_6H_{12}O_6$, each having its own properties and its own peculiar physiological behavior. One of these types is called glucose and another is fructose. It is said that such a hexose sugar as glucose is the primary fuel used in all protoplasmic activities. It contains potential energy. It was formed in light and the energy of the light is locked up in it. Within the organism, combination with oxygen releases this energy. This type of sugar is in solution in the protoplasm of the cell. When a molecule of glucose and one of fructose are united with the loss of one molecule of water, another type, $C_{12}H_{22}O_{11}$, *cane sugar*, is formed. This is present in varying quantities in plants, particularly in the stem of the sugar cane and in the fleshy root of the sugar beet. When cane sugar is eaten by man, it is *digested* into glucose, $C_6H_{12}O_6$, in which form it circulates to the tissues. Cane sugar solution acts as a poison when injected directly into the blood. Another carbohydrate type of compound is *starch*. Its formula is a *multiple of* $C_6H_{10}O_5$. Common examples are wheat flour, potato, tapioca and corn starch. It is in the form of starch that carbohydrates are stored as reserve fuel supply in plants, to be used in further life processes. Surrounding the embryo in the seed is starch, to be used by the embryo during germination. Animals do not store up any great amount of carbohydrate fuel. Some animal starch or glycogen is temporarily stored in the liver and less in the muscles. It is present in considerable quantity in digestive glands of oysters. The cellulose of plant cells is a carbohydrate compound, not easily digested by most animals, although the goat is an exception to this rule. Gums, such as gum arabic, are also carbohydrate compounds made by plants.

Fats. They are storage compounds, reservoirs of energy, and are present in many plants and animals. They are synthetic products of cell activity. Protoplasm contains *fat-like* compounds called phosphatides. Fat is a compound of carbon, hydrogen and oxygen. They are triglycerides of fatty acids such as palmitic, oleic and stearic. The phosphatides consist of fat combined with phosphoric acid and an organic base, a derivative of ammonia. They probably exert an influence on the permeability of the cell membrane, a matter of fundamental importance in cell life. Fats deposited in tissues are derived principally from fats or carbohydrates ingested. There is some indication that part of the protein molecule can be converted into fat. Fat can also be converted by the living organism into sugar. This possibility of transformation is one illustration of the unique property of protoplasm. Fat has twice the heating or energy value of sugar and is burned for this purpose in the body. The diet of Eskimos is almost entirely meat, *i.e.*, proteins and fats. In plants, fat is stored in seeds such as those of the peanut, cocoanut, cotton and flax plant. In animals it is stored in a type of connective tissue called adipose tissue.

Physical Chemistry of Protoplasm

Colloids. Protoplasm is a colloid. The name *colloid* was introduced in 1861 by Graham. It is derived from a Greek word meaning 'glue.' Glue is derived from gelatin and gelatin is a protein and also a colloid. Colloid is not a name for a special chemical compound but for a *state of matter*. If small particles of gold are shaken up in water, they settle to the bottom in a short time. If they are divided into *very small* particles, these will remain suspended for a time, but *may* gradually settle. Such a combination of water and gold is called colloidal gold. Any active portion of the world studied by itself is called a *system*. If it is alike in every part, it is a *homogeneous* system. Gold is a homogeneous system. A system composed of unlike parts is *heterogeneous.* Colloidal gold is a heterogeneous system. A heterogeneous system can be separated into its constituent parts or phases. Colloidal gold has two phases: first, the *continuous* phase, *i.e.*, water; second, distributed throughout this are the fine gold particles, the *dispersed phase.* A colloid is unlike a solution of water and sugar or sodium chloride. In the latter case the solvent, water, separates the sugar or salt into individual *molecules* or *ions* which are evenly distributed through the water. Such a solution is crystalloidal. Crystalloids in solution diffuse through membranes quite easily and can be recovered as crystals from the solvent. In colloidal solutions the dispersed phase consists of fine particles which are multimolecular and small enough to remain suspended but too large to diffuse through membranes.

There are a number of types. In the first place, a *sol* is a colloid in which the particles are *ultramicroscopic* in size and there is a relatively wide range of movement between the dispersed particles, *i.e.*, sols are fluid-like in nature; they have little viscosity. On the other hand, a *gel* is that condition in which there is little range of movement between the dispersed particles; gels are very viscous and form a jelly. Some colloids can change from the sol to the gel state and back again. Gelatin is an example of this. If the temperature is raised, it becomes a *sol*, while if the temperature is lowered, it becomes a *gel*. This is an illustration of a reversible reaction quite characteristic of protein colloids. The contraction and relaxation of muscle is possibly of this nature, *i.e.*, the change from a sol to a gel and the reverse. Mast explains *amoeboid* movement in this way. On the other hand, the clotting of blood is an example of an irreversible reaction, a change from the sol state to a permanent gel state.

Various conditions of sols have been distinguished. First: Suspensions, in which the minute bodies separate out by gravity if allowed to stand. Smoke is an example of this. The dispersed phase consists of minute particles of carbon distributed in air, the continuous phase. Second: Suspensoids in which *ultramicroscopic* bodies are dispersed in a fluid medium. They do *not* settle out. They do not gel and are easily precipitated by salts. Third: Emulsions are sols in which the dispersed phase consists of minute particles of liquid in a liquid continuous phase. The two liquids do not mix. Cream contains minute droplets of oil dispersed in water, while butter is another type of emulsion in which the minute droplets of water are dispersed in butter fat (oil). Fourth: An emulsoid is a sol resembling an emulsion but more viscous and may become semi-solid or even a gel. In the gel state it contains considerable water and will not gel if too much water is present. *Proteins are emulsoid gels.* They dissolve easily and have a great affinity for water. We have already noted how gelatin can be changed from sol to gel, or gel to sol. White of egg (albumen), on the other hand, coagulates on heating, *i.e.*, forms an irreversible gel. Starch forms a gummy paste when heated carefully in water and is then an emulsoid. Suspensoid states grade into the emulsoid states. The alveolar theory of the physical nature of protoplasm developed by Bütschli agrees with the conception that protoplasm is an emulsoid gel. It is perhaps more correct to say that several emulsoids occur in protoplasm in the same aqueous medium. Protoplasm is a polyphase colloidal solution. The same water holds in solution many crystalloids, such as NaCl, KCl, Na_2SO_4, Na_2CO_3, as well as sugars. The phosphatides are emulsoids.

The thousandth part of a micron is called a submicron and is represented by the letters '$\mu\mu$.' A submicron is a millionth of a millimeter. It is possible with the aid of the ultra-microscope to estimate the size of colloidal particles. It is estimated that particles, *i.e.*, molecules or ions, in true solution (crystalloidal) are never larger than 0.1 $\mu\mu$. Colloidal gold particles have a diameter of *about* 1 $\mu\mu$. It is thought that each suspended particle consists of hundreds of gold molecules. In emulsions of oil and water the oil particles are probably about 1000 $\mu\mu$ in diameter.

Brownian Movement. A suspensoid consists of ultramicroscopic particles that bear electric charges of the same sign and hence repel each other in their movements in the solution. This is true also of the dispersed phase of an emulsoid. In 1827, Brown, who later discovered the nucleus in plant cells, saw a movement of microscopical bodies in a suspension. The particles danced around a fixed point, first here, then there. This is known as the *Brownian Movement.* It can be observed under ordinary microscopic magnification in finely powdered carmine rubbed in water. The rate of movement increases with the decrease in size of the particles, and with the increase in temperature. The movements of fine suspensions, seen with the ultramicroscope, are considered to be identical with the "Brownian" movements. It is not ordinarily visible in protoplasm until this is made fluid, from which it has been concluded that protoplasm is usually in the gel state. If the electric charges of the dispersed phase are removed by the introduction of ions having opposite electric charges, then the dispersed particles settle or a gel may form.

Ionization. Some substances called *electrolytes*, dissolved in water, conduct an electric current, — for example, sodium chloride — while others, such as sugar, do not. It has been found that the molecules of substances which *do* conduct the electric current separate when in solution into portions called *ions*. Moreover, ions carry either positive or negative charges of electricity. The positively charged ions are called *cations;* the negatively charged are *anions*. Such solutions are known as *electrolytes*. If electrodes connected with a battery are placed in such a solution, then it is found that the positively charged ions (cations) collect at the cathode (−) and the negatively charged ions (anions) collect at the anode (+). The word *cation* means ' going down ' and *anion*, ' going up.' Not all the molecules of an electrolyte necessarily ionize. But let us illustrate what takes place in the electrolytes found in protoplasm. Hydrochloric acid, if present, forms H^+ (cation) and Cl^- (anion) ions; Sodium chloride, Na^+ and Cl^- ions; H^+ ions are formed if acids are present; OH^- ions when bases occur. Sodium, potassium and calcium salts have Na^+, K^+ and Ca^{++} ions. Ammonium salts have an NH_4^+ ion and nitrates have an NO_3^- ion, sulphates have an SO_4^- ion. It is evident that ions may be more than simple atoms. The degree of dissociation is related to the degree of dilution. If complete dissociation of NaCl took place, the number of particles in solution would be twice the number of molecules of salt added at the beginning of the experiment. Ordinarily dissociation approaches this point but does not reach it. Sugar does not form ions in solution and is therefore an example of a nonelectrolyte. It is now believed that even proteins may ionize — for example, an unattached carboxyl group may give off a positively charged H^+ (cation) while the remainder of the great molecule will bear a negative charge, *i.e.*, act as an anion. Ionization of living matter aids in the formation of an endless variety of combinations and disintegrations so characteristic of cell life. Some investigators say that the electrical charges carried by the ions of salts in solution contribute vital qualities to the colloidal proteins and phosphatides. Every functional activity of cells is accompanied by electrical discharges which indicate that electric phenomena are concerned in cell processes.

Hydrogen-Ion Concentration. Some solutions are acid and others are alkaline. It has been found that acidity is due to an excess of free hydrogen ions, and alkalinity to an excess of hydroxyl (OH) ions. Accurate methods are now available for determining the reaction of fluids. The degree of acidity or alkalinity is expressed in terms of the hydrogen-ion concentration, *i.e.*, designated by the symbol "pH." A pH of 7.0 means a neutral solution. Babor says: "The essential reaction of neutralization is the union of the hydrogen and hydroxyl ions to form water."[1] A number smaller than pH 7, as, for example, pH 5, means an acid condition, while a number greater than pH 7, as, for example, pH 8, means alkalinity. A normal solution of an acid would be pH 0; while a pH of 14.0 would represent a normal solution of an alkali. The range for protoplasm is said to be from 5.5 to 9.5. The fluids of the human body to which the cells are adjusted are slightly alkaline, *i.e.*, pH 7.3^+, and the slightest departure from this 'equilibrium' is of serious moment. pH has an important bearing on the relation of the dissolved salts to proteins and phosphatides.

Cell Membrane. Most cells are separated from each other by, or enclosed in, a *membrane* which holds intact the physico-chemical system within. The cellulose wall of plant cells is *not* their cell membrane. In this case the membrane is the superficial film of protoplasm just within the inner cellulose surface. Substances necessary for intracellular vital processes must pass in and out through the cell membrane so that the physiological importance of the latter is evident. It is composed largely of proteins and phosphatides. It is a film of somewhat condensed protoplasm. The following physical phenomena play a large part in membrane physiology.

Surface Tension, Absorption and Adsorption. Liquids possess a surface property known as surface tension. When some other substance (gas, liquid and solid) comes in contact with a liquid, the movement of its molecules will be restricted and the outer layer will thus acquire a more solid property, producing a surface film. Cell membranes possess the property of surface tension and the latter plays an important part in the *absorption* of water into the cell. It is evident that internal changes in cell protoplasm change the surface tension of the cell membrane and therefore change the amount of absorption of water, for example. This is constantly varying. Excess of hydrogen ions increases the attraction of proteins for water, while salts sometimes have the opposite effect. It is known that water which has a disagreeable odor may be purified by passing it through powdered charcoal. In certain cases a dye may be separated from its solute, water, by passing it through such a filter. The dye, methyl violet, is taken up by gelatin. This is not a case of *absorption.* In absorption the substance absorbed permeates the absorbing medium. Absorption occurs in cells. To a certain extent it is a diffusion. The illustrations just given are examples of a different physical phenomenon, namely, *adsorption.* The odoriferous particles in the water or those of the dye are condensed on the surface of the charcoal particles. The methyl violet is *adsorbed* on the surface of the fine particles of the dispersed phase of gelatin. The particles which *adsorb* do so because their surfaces possess unsatisfied free energy due in part to their surface tension properties. It can be seen that colloids are especially well fitted to display this property of adsorption on account of the relatively great surface area of the multitude of ultramicroscopic particles of the dispersed phase. To illustrate: a mass 6 cm. × 6 cm. × 6 cm. has an area of 216 sq. cm.; while if the same mass is separated into cubes 1 cm. × 1 cm. × 1 cm., the total surface area of all the smaller cubes is 1276 sq. cm. If the same mass were divided into millions of fine particles similar to those of a colloidal sol, it is evident that a still greater surface area would be presented. The degree of adsorption depends on the amount of surface presented, because at the surface there is free energy, which is the basis for the adsorption association. It is regarded as a sort of weak chemical union, but not of the usual type in which atoms or groups of atoms unite in definite proportions. Adsorption in a protoplasmic system, because it reduces the free energy, tends to produce a stable equilibrium — but in the living cell, static equilibrium is not attained but is constantly prevented by other forces.

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[1] For example a combination of solutions of NaOH and HCl becomes neutral when *all* the OH^- and H^+ ions unite to form H_2O. The other ions form NaCl.

Filtration. This has been described as the process by which a liquid is separated from a solid by passing it through a porous substance called a filter which retains the solid. It has been suggested that elimination of water from blood through the cells which form part of the excretory tubules of a vertebrate kidney is a filtration process. The pressure of the blood takes the place of gravity, which is the usual filtration force in the laboratory. Cell membranes exhibit the properties of a filter.

Diffusion. When certain dyes are added to water, small particles of dye dislodge themselves and move through the water until the entire mass of the dye is evenly distributed. If sugar crystals are added to water the same thing takes place. This process of even distribution of molecules of one substance between the molecules of another is known as diffusion. When substances are absorbed into cells, they also *diffuse* throughout the protoplasm. Nitrates diffuse through the cell membranes of the root-hair cells of plants — a matter of vital importance to plant and animal life.

Dialysis. If we place a quantity of egg albumen, salt and water in a parchment tube and suspend this in a beaker of water and later test the water, we will obtain positive tests for salt but not for albumen. The membrane is permeable to salt but not to albumen. This technic is used in separating proteins (colloids) from inorganic salts (crystalloids) when both are present in the same solution, since proteins as a rule are not diffusible through the parchment used.

The cell membrane exhibits this property of selective permeability, *i.e.*, dialysis, but the cell membrane has a far wider range of permeability properties than lifeless parchment membranes.

Osmotic Pressure. Membranes are known to differ in permeability. Some membranes will not permit dissolved substances to pass through them but will permit water or the solvent to do so. These are called semi-permeable membranes. If we tie a piece of such a membrane over the end of a thistle tube, fill the bowl of the tube with a strong solution of salt or sugar and immerse this in a vessel of water, we will find sometime later that liquid rises in the stem for some distance. Water has passed from the vessel through the membrane into the tube, diluting the solution, but the particles in solution do not pass through in the reverse direction or at most but very little. If we made the rising column of liquid press against a weight, we would have evidence of considerable force. Such a force is known as osmotic pressure. It is the diffusion pressure of dissolved substances. It therefore exists in solution, even though it is not demonstrated as in the illustration. It increases with the concentration and decreases with dilution. Not only molecules but ions present behave as molecules in determining its amount. Therefore it is a measure of molecular concentration although the ionization of the dissolved substance must be considered. A completely ionized substance such as sodium chloride would have twice the osmotic pressure as the same substance in molecular distribution in the solvent. With very strong membranes, columns of water 75 feet high have been raised by osmotic pressure. The movement of water is always toward the more concentrated solution. The osmotic pressure within the cells of the human body is equal to that of a 0.9% NaCl solution. The fluids bathing the cells have about the same osmotic pressure. The two are said to be isotonic. If the blood contains more concentrated salts than those of the cells, then it is said to be hypertonic. If less salts, its osmotic pressure is less and it is said to be hypotonic. If we place red blood cells in a hypotonic solution, the red cell swells and bursts. Endosmosis has occurred. If we place the cell in a hypertonic solution, water diffuses out and the cell shrinks. Exosmosis has occurred. The osmotic pressure of root-hair sap is hypertonic to soil water, hence endosmosis occurs. It is thought that variations in the osmotic equilibrium between the cells and their environment is a normal part of the physiological condition, but that the tendency is always toward an osmotic equilibrium. Cell membranes permit the passage of some substances through but not others. Cell colloids do not pass out through it. The condition of the membrane varies from time to time. Certain aspects of membrane permeability do not appear to be explained by what we know *now* about diffusion, dialysis and osmosis. Most of our present knowledge of these processes has been determined by the use of non-living membranes while the cell membrane is a living colloid. It appears to possess properties of which we know little at present. The great amount of research today as to the nature of the cell membrane indicates that biophysicists regard it as one of the keys to the understanding of vital processes.

Types of Reaction. A review of our study of the formation of proteins from amino-acids and the reverse of the process and also the synthesis of carbohydrates and disintegration of the same, all point to the fact that many kinds of reaction take place within the cell. The most complicated reactions take place with the greatest ease. In this factory everything is orderly. Different processes apparently occur in different parts of the factory at the same time. The physiological chemist has so far been more successful in *analyzing* complex proteins and has thrown light on just how disintegration of complex compounds takes place. He also knows *something* about the *manufacture* or synthesis of proteins from amino-acids and he has actually made them. Although these synthetic products resemble compound proteins, it is felt that they are not identical with natural proteins.

As yet the bio-chemist cannot readily imitate the greatest of all biological reactions — namely, the synthesis of carbohydrate from carbon dioxide and water by the energy of the sunlight in a field of chlorophyll. Balz appears to have succeeded in making sugars in the presence of MgO_2 (present in chlorophyll), but his process requires much more energy than does the natural process.

Among the types of reactions known to take place are:

1. *Hydrolysis:* In this case a molecule of water is added to a molecule of some other substance and then the combination is split into two molecules of some simpler compound. Cane sugar plus water is reduced to glucose and fructose as illustrated in the following equation: $C_{12}H_{22}O_{11} + H_2O = 2(C_6H_{12}O_6)$. This process, involving the taking up of water (*i.e.*, the loss of water), is called hydrolysis. Complex proteins taken in with food are by successive hydrolyses reduced to amino-acids in the intestine, and only these can be absorbed and circulate in the blood. In the day's work within the cell, hydrolysis occurs over and over again.

2. *Dehydration Synthesis:* This is the opposite process. Complex compounds rich in energy are built up from simpler compounds. For example, a molecule of glucose and one of fructose can unite with the liberation of one water molecule, resulting in cane sugar. In the discussion of amino-acids, the formation of glycine-glycine from amino-acids was of the same nature. Many reactions within the organism are of this sort.

3. *Oxidation:* The basic fuel supply or source of energy for the cell is a simple sugar like glucose. When a plant organizes sugar from CO_2 and H_2O, oxygen is liberated and energy stored. To release this energy it is evident that oxygen must again be combined with sugar. Such a combination or combustion by oxidation occurs in cells. Matthews says: " The discovery of the origin of the energy of living protoplasm in the combustion of carbon and hydrogen was one of the greatest and most fundamental discoveries of chemical biology." The pioneer in this work was that " benefactor of humanity," the chemist, Lavoisier, put to death by the proletariat of the French Revolution.

Enzymes. The above processes of hydrolysis, dehydration, synthesis and oxidation would take place very slowly in protoplasm if it were not for the presence of catalysts known as enzymes. Enzymes are organic catalysts, probably protein compounds and colloidal. They hasten chemical reactions in the cell. They act when present in but small quantities; they are not changed by the changes they bring about. Increase in temperature hastens the reaction up to a certain optimum which in warm-blooded animals is about the temperature of the body. If the temperature is increased beyond this, the enzyme is destroyed. Some enzymes are intracellular, some produced by cells are secreted from them and act outside. Pepsin powder sold by the druggist is dried extract of the gastric glands mixed with inert ingredients and yet the enzyme retains its hydrolytic power long after it has been separated from the living tissue. There are many enzymes and many kinds. They are specific, some acting in an acid medium, some in an alkaline medium, some acting on proteins, others on carbohydrates, others on fats. Some enzymes known to be present in the blood are prevented from acting by the presence of *anti-enzymes*. Coagulation of the blood while circulating in the body is prevented by the presence of an anti-enzyme. When bleeding occurs, the anti-enzyme is otherwise engaged, thus freeing the enzyme to initiate coagulation, which, as already stated, is a transition from a sol to an irreversible gel. Cells apparently possess enzymes that would, if allowed to act, disintegrate the compounds of the cell. Anti-enzymes prevent this. At death, the disintegration enzyme is released and the organ undergoes dissolution. This process is known as *autolysis*. The organization of protoplasmic systems carries along agents of dissolution which operate at death, even in the absence of bacteria, and so make possible the nitrogen cycle.

Vitamins and Hormones. Although these substances are described in more detail elsewhere (page 429), yet they should be mentioned here as compounds which somehow are concerned with cell processes. They are products of cell manufacture, and are present in *very small* quantities. So far as we know, vitamins are of plant origin, but are as important for animal life as any other compounds. Animals, however, make hormones. In some cases the hormone is made by one part of the organism to be functional in another part. They have been called chemical messengers, bringing about integration of organ functions so that the entire assemblage of organs can act as an individual. They are an adjunct to the nervous system in this work.

Gases. Oxygen is necessary for cell metabolism. It is absorbed through the cell membrane and plays a part in reactions within the cell. A by-product of oxidation is carbon dioxide, which is excreted.

PART III — CELL PHYSIOLOGY

The structures described in the section on cell morphology, and the compounds and processes presented in the section on the physics and chemistry of protoplasm are concerned in cell physiology. The word *metabolism,* used by physiologists, refers to all the chemical reactions which take place in protoplasm. Metabolism is for convenience divided into two groups of processes, (*a*) *anabolism,* or those synthetic processes by which the complex protoplasmic compounds are built from simpler initial compounds and (*b*) *katabolism,* which refers to processes of analysis or destruction by which complex protoplasmic compounds are broken down into waste products. Both groups are concerned with cell physiology. The irritability of cells must be considered in any discussion of cell physiology.

Cells or *organisms* are going concerns, temporary organizations which maintain for a time a dynamic physico-chemical system in a universe of physico-chemical systems of a different sort. The organic physico-chemical system, be it cell or organism, possesses a property very seldom thought of, but very fundamental, namely, the property of *persistability.*

We noted in our study of protoplasm that within the cell there is a constant tendency toward the establishment of a static equilibrium and that this tendency is constantly checked. The cell is staggering as it were toward death from the moment of its origin. During life reactions are reversible — death comes when they are irreversible. The cell or the organism *tends* to continue its organization. The cell is an energy transformer, and since in maintaining its individuality it gives out energy constantly, it must acquire energy from without. The world acts on it and it reacts on the world. Physiology is therefore an analysis of how such a system is maintained under the conditions present.

Not only is there a general similarity in morphology among the many kinds of cells, but there is also a basic similarity in function; and yet over and above the underlying similarity there occurs specialization in structure and function. The physiologist finds in all the multiplicity of forms of cells in organisms, either simple or complex, unicellular or multicellular but a *few* kinds of physiological processes.

In discussing the physiology of a cell we are confronted with a difficulty due to the fact that in some cases, the organism is but a *single* cell; in other cases a *multicellular* individual consisting of a great many cells of different kinds. Long ago, Schleiden called attention to the fact that any one cell of a multicellular organism carried on a double life — first, activities which concerned itself as an individual entity; second, those activities that had to do with the part it played in the entire organization. It is this complex which renders difficult the discussion of cell physiology.

A single-celled organism such as the Amoeba is a "jack of all trades." It is an independent organism capable of maintaining existence. It performs the following functions: ingestion, secretion, digestion, respiration, circulation and metabolism which includes excretion. It adjusts itself through sensation, conduction and contraction, and it reproduces. And it has a limited control over nature.

On the other hand, the cells of Metazoa, and especially those of higher Metazoa, such as Mammals, are specialists. Consideration of the physiology of such cells, involves the distinction between their basic activities common to all and special activities which distinguish one special type from another.

Basic Metabolism. In the first place every cell must be a *going concern*, capable of work necessitated by the fact that it is a system in the midst of other systems. Physiologists now recognize that a distinct part of every cell's life is concerned with its maintenance. This is known as basal metabolism. In basal metabolism a small amount of protein is used up and as constantly replaced. A certain amount of free energy is always present however.

Functional Metabolism. Physiologists have found that *over and above their basal metabolism, specialized cells* exhibit what is known as functional metabolism. Let us consider some of these special jobs.

(*a*) *Sensory cells.* These are said to possess the property of irritability. The protoplasm is in a state of somewhat stable equilibrium which is upset by sudden changes in the external medium. When its equilibrium is thus upset, the cell is said to have been stimulated and the external agent causing this is called a stimulus. Sensory cells in the retina are stimulated by sudden changes in color or intensity of light; the stimulus in the case of the sensory cells of the ear is a succession of sound waves. Such stimuli are physical and others of the same type are (*a*) sudden mechanical contacts with special sensory cells, (*b*) sudden changes of temperature which stimulate special sensory cells, (*c*) sudden changes in strength of electrical current. Stimuli are also chemical, such as the sudden presence of food in an empty stomach or of water or salts, etc.

(*b*) *Nerve cells* (Fig. 319). Adjustment of the organism as a whole may be necessary, involving organs of locomotion. The change brought about in the stimulated sensory cell is communicated to a nerve cell and upsets *its* equilibrium, initiating what is known as a nerve impulse, which is a change propagated over the long process of the nerve cell. The progress of the impulse is the functional metabolism of the nerve cell, which in turn upsets the chemical equilibrium, in a muscle cell, for example. The functional metabolism of a nerve cell is called *conduction*.

(*c*) *Muscle cell.*[1] The change in the muscle cell (Fig. 318) effected by the nerve impulse is evidenced by its functional metabolism, known as a *contraction*. The cell becomes shorter and thicker. The movement of a higher Vertebrate is not accomplished by the contraction of muscles alone, but these are connected with skeletal and other structures, forming a mechanism of moving levers, making locomotion possible.

The sensing, acquiring and ingestion of food requires the cooperation of sensory, nerve and muscle cells and many others also.

(*d*) *Gland cells.* Compound proteins, carbohydrates and fats eaten must be broken down into simpler compounds to be of use in basic and functional metabolism of all cells of the organism. The cells of many glands manufacture enzymes which do the work of *digestion*. The gland cells perform the special work of *secretion*. Digestion does not occur within the cells of Metazoans but in tubes formed of cells. It is part of the functional metabolism of cells *lining* the digestive tract to form the container in which digestion takes place and another function is to absorb the digested products.

(*e*) *Cells of Respiratory Membranes.* The functional metabolism of these cells in part is to absorb oxygen and to hand this over to the blood. The functional metabolism of many other cells brings oxygen to the respiratory membranes.

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[1] In higher animals, the histologic unit of skeletal muscle is not a single cell but a multicellular syncytium of cells called a muscle fiber.

(*f*) *Cells of the transport system.* Foods absorbed from the intestinal cavity and oxygen from the respiratory membranes pass into the *blood.* This is contained in a system of tubes and in many cases propelled by a muscular pump. Heart, arteries, veins and capillaries are composed of a multitude of various kinds of cells whose functional metabolism is the transportation of oxygen, amino-acids, glucose, fats, water, salts, vitamins and hormones throughout the body, *i.e.*, to bring them to *all* the cells of the body.

(*g*) *Cells of the excretory system.* Every cell excretes wastes of basic and functional metabolism. In a higher Vertebrate, such wastes find their way into the transport system. The functional metabolism of some cells, such as those of the kidney and urinary system, are concerned in eliminating some of these wastes from the body.

The functioning of secreting, digesting, circulating, respiratory systems furnish materials for basic and functional metabolism of *all cells.* A cell in the pancreas (Fig. 291), for example, secretes *trypsin,* which aids in the preparation of amino-acids which may be used in the metabolism of *that pancreas cell or any other cell.* Functional metabolism results in a greater energy exchange than is needed in basic metabolism. In every cell there is a period when only basic metabolism occurs. This is called its *resting* period. But basic metabolism must continue *during* functional metabolism. During the functional metabolism of a gland cell, the latter is elaborating compounds absorbed, especially protein compounds. During the metabolism of a muscle cell it is chiefly the carbohydrate glycogen that is involved. Very little energy exchange occurs during the metabolism of a nerve cell. Connected with the consideration of the functional metabolism of specialized cells is the significant fact that *the life of the organism as a whole is not the mere sum*

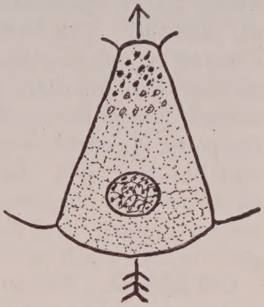

FIG. 291. — Diagram of a pancreas cell. Nucleus is near base. At this end, materials are absorbed. At the narrow end are indicated granules which are discharged as secretion. The arrow indicates *polarity.*

total of the activities of its various cells. Each cell is a part of an organization. The persistence of the system as a whole depends on the cooperative work of all its units.

(*h*) *Cells of the reproductive system.* The general effect of basic and functional metabolism is the persistence of this community of cells for a longer or shorter period. Both the constituent cells and the organism as a whole possess the property of *persistability.* But it is also a characteristic of unicellular or multicellular organisms that the dynamic system which they constitute has a limited period of existence. And yet the persistability property carries the particular *type* of organization beyond the period of its own individual existence. This remarkable phenomenon is accomplished by a special type of functional metabolism called reproduction. Cell division is an important feature in the development of plants and animals and in fact occurs all through the life period. In plants the power is restricted to the cambium and to formative cells in root tips and buds. In mature higher Vertebrates it occurs in all tissues with few exceptions, as, for example, in the cells of the nervous system. Cell division is so important in embryology and genetics that it will be considered in some detail.

Cell Division. The most intensive period of cell reproduction or division is during embryonic life. Yet it is not limited to this period. The cambium cells of ancient redwood trees are still continuing a process of cell divisions which began in the same trees, thirty centuries or more ago. Indeed, strange as it may seem, the cell divisions constantly taking place in one's own body are continuations of a process which was initiated unknown ages ago, back at the beginning of all life.

Amitosis. In a few cases, such as old tissues, some parasites and Protozoa, the nucleus, *appears* to divide by *simple* fission and this is followed by division of the cytoplasm. Probably most supposed cases of this sort are really of the type to be presently described. Most cells divide by a complicated and *Indirect* method. The former is now called Amitosis and the latter, indirect method, is known as *Mitosis.* Knowledge of this was gained between the years 1873 and 1882. In the latter year, Flemming suggested the name Mitosis for the process.

Mitosis. In mitosis several changes take place simultaneously in the cell. Therefore, a description is difficult. Moreover, the process is continuous, but for convenience of presentation it is divided into four successive phases. 1. *Prophase;* 2. *Metaphase;* 3. *Anaphase;* 4. *Telophase.* The following description is generalized, *i.e.*, it represents what is true of most cells. To understand it, a picture of a cell prior to mitosis, *i.e.*, a *resting cell,* must be studied. In this stage the cell wall is intact, and the nucleus in the interior has a nuclear membrane. A nucleolus may be present. Chromatin granules are clustered about the linin network, forming karyosomes where linin fibers cross each other.

1. *Prophase* (Fig. 292 — P^1–P^4). As mitosis begins the chromatin exhibits a greater affinity for certain dyes, showing that chemical changes are taking place. The chromatin granules assemble themselves to form a long thread, skein or spireme coiled somewhat intricately at first, but less so later on. The Greek word for *thread* is "mitos." In the meantime the nuclear wall and the nucleolus are disappearing. The centrosome outside the nucleus divides and each of these centrosomes moves away from the other. Around each centrosome appear radiating lines which form an aster (star). As the centrosomes diverge more or less slightly, fibers appear between them. The two centrosomes move away and down and around, each 90° from their starting place, so that they come to rest at opposite sides of the cell, 180° apart. An axis passing through them is at right angles to a plane which would pass through the original centrosome and through the center of the nucleus. The lines from the asters now extend in all directions out toward the cell wall. "Spindle" fibers extend across the cell between the two centrosomes. Spindle and asters are known

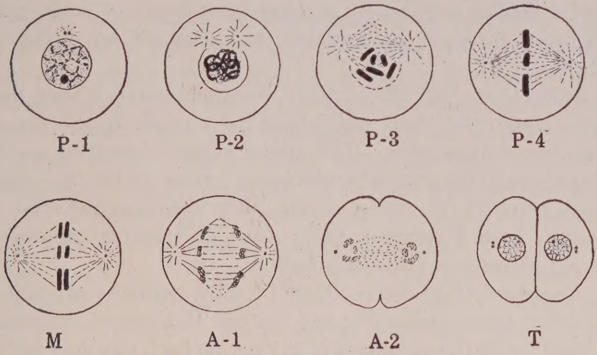

FIG. 292. — Indirect cell division or Mitosis.

as the *amphiaster*, or *achromatic* figure. What are these lines? Are they actual fibers or are they lines of force which have gathered protoplasmic granules along their course? The later behavior indicates that such physical properties as elasticity or tension are present. These spindle fibers penetrate in among the coils of the spireme. The *spireme* (chromatin thread) has divided into a number of pieces called *chromosomes* — the number being quite definite for each form of life. Thus in Hydra there are 12; in Lumbricus, 32; in Cambarus, 200; Anopheles, 6; in Drosophila, 8; Musca, 12; Rana, 26; Columba, 16; Equus, 60; Macacus, 48; Man, 48; Spirogyra, 24; Fucus, 64; Pinus, 24; Pisum, 14; Primrose, 36; Zea mays, 20; Allium, 16; Lilium, 24. Possession of a similar number of chromosomes does not mean genetic relationship because some plants and animals have the same number.

2. *Metaphase* (Fig. 292 — *M*). The chromosomes have moved into the equatorial plane which is at right angles to the axis joining the two centrosomes. This plane is that described above as passing through the original centrosome. Some of the fibers appear to be attached to the chromosomes. The chromosomes split longitudinally, each forming a pair. Careful examination indicates that *each chromosome* is *exactly halved.*

3. *Anaphase* (Fig. 292 — A^1–A^2). The members of each pair move away from each other and toward the nearest centrosome. The function of the anaphase is to provide each *daughter* cell with the same number of chromosomes possessed by the *mother* cell. Late in the anaphase a groove appears in the cell membrane where the equatorial plane coincides with it. In plant cells small granules appear on the spindle fibers just where this plane passes through them.

4. *Telophase* (Fig. 292 — *T*). This is the reconstruction of two new daughter nuclei and cells. The chromosome groups on each side pass over to their respective centrosomes, and then the spindle and aster fibers and chromosomes begin to disintegrate. The groove in the cytoplasm deepens and two daughter masses of cytoplasm are formed, each with its own cell wall. A new nuclear wall is formed in each and inside is nucleoplasm, linin network, chromioles and a reformed nucleolus. By this time the centrosomes in each may divide in preparation for the next division and then fade away to reappear when each daughter cell is about to

divide again. In the active cell division period of embryonic life, cells sometimes divide so rapidly for a time that they have no time to grow. That is, after repeated cell divisions of the fertilized egg, the embryo consists of hundreds of cells, each but a small part of the original size of the egg. There are many variations in the details of the process. For example, in higher plants there are no centrosomes; in some cells the formation of a spireme is omitted. In plant cells there is no constriction by cleavage of the cell wall when in the telophase, because the cell wall is of cellulose. A cellulose wall is built up in the equatorial plane, but it should be remembered that this new cellulose is not hard and rigid, but soft and fibrous.

What is the meaning of this complicated process? Apparently it is a most particular kind of division and the answer to the question seems to be that by mitosis *each daughter cell is insured an equal equipment of chromatin, the exact counterpart of that of the mother cell.* The bearing of this on heredity will be made plain later. What are the causes of cell divison? It has been found that reduction of the surface tension by chemical means causes certain eggs to divide; that the viscosity of the dividing cells increases up through the prophase and then decreases; also that the rate of oxidation increases and then decreases and that changes in electrical potential occur. But these are mere statements of observed physical and chemical changes which occur and which staining technique long before indicated. At present the causes of mitosis are not known.

Growth Metabolism. When a single cell divides into daughter cells, the latter are each half the size of the parent cell. Normally, they grow to the mature size. In the formation of spores, growth does not immediately take place, for the period of successive cell divisions results in smaller and smaller cells until the spore type is produced. In early cleavage stages of zygotes, the period is characterized by the production of smaller and smaller cells. But in *many* cases, cell division is followed by growth. This involves not only basic metabolism but also the formation of *more* protoplasm, hence the name growth metabolism. The energy stored is in excess of the energy dissipated. Growth metabolism is a distinct feature of development since development involves an ever greater increase in cell numbers. Growth involves increase in size, the formation of more cells, greater amounts of intercellular substances, more protoplasm. It also involves the differentiation from the somewhat spherical type of embryonic cell to all the cell varieties of the adult. Growth involves also the elaboration of an independent organization as development reaches it climax. During maturity, it has been found that the amount of nitrogenous compounds needed for basic metabolism averages about the same from day to day. The excess needed in functional metabolism is not so great as one might expect. But growth metabolism does demand an excess. In other words, the growing child needs actually more nitrogenous compounds than a grown person. It is from this material that the new cells are fashioned.

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CHAPTER XIX

EMBRYOLOGY

Introduction. As human beings, born with the deep-seated urge for self-preservation, we regard the individual as of supreme importance. The various physiological activities comprising metabolism and adjustment are sufficient of themselves to secure the welfare of the individual. And yet there remains the function of reproduction exhibited by all animals and plants. What is the meaning of this? As far as the individual is concerned, the exercise of this function is unnecessary for the maintenance of life. We must look beyond the individual for the answer. The function of reproduction present in individuals secures the continuance of the species. If we regard the individual in respect to metabolism and adjustment as an active physico-chemical organization *sui generis*, we must also regard it as *supremely unique* in its ability to insure the continuance of that organization by the exercise of the function of reproduction.

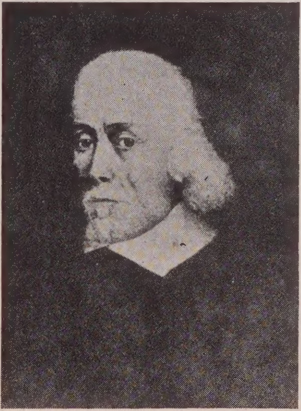

FIG. 293. — William Harvey, discoverer of circulation of the blood. From Locy: *Biology and Its Makers.* Courtesy Henry Holt & Co.

Biogenesis. In the seventeenth century, William Harvey (Fig. 293), the discoverer of the circulation of the blood, studied the embryonic development of the chicken from the egg and believed that he had discovered a universal law of biology, namely, that "all life comes from the egg." But the examples of reproduction by fission, budding, parthenogenesis and spores demonstrates that Harvey's statement must be modified.

It *was* modified many years later to "all living things come from living things."

But this law of *Biogenesis* was not established until about 1876. Prior to that time it was generally believed that many organisms originated from non-living matter by "spontaneous generation," as it was called, and this is the theory of *Abiogenesis*. It was very natural for Aristotle, in the third century, B.C., to conclude that insects and frogs arose from mud. Bees, flies, mice and rats were for a long time supposed to have originated in this way. Even Alexander Ross, in the eighteenth century, sarcastically wrote that "to question this, is to question reason, sense and experience." In every age, some *authorities* make dogmatic assertions which are without basis in experience.

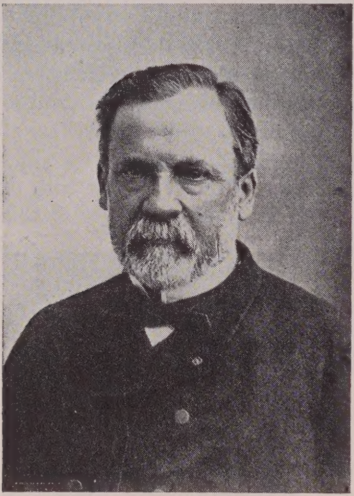
FIG. 294. — Louis Pasteur, great bacteriologist.

In 1668, Francesco Redi, an Italian, tested experimentally one of these imagined cases of spontaneous generation. He placed meat in several jars, some of which he left open, and covered others, some with wire gauze and some with parchment paper. The meat in all the jars decayed. Maggots (fly larvae) and, in time, flies appeared in the *open* jars. Neither maggots nor flies appeared in the *parchment-covered* jars. This showed that when flies could not get to the meat, there was no spontaneous generation. Flies lay eggs in decaying meat, and the eggs develop into flies. Flies come from flies. Other workers verified these results. Toward the end of the seventeenth century the compound microscope appeared and, with the aid of it, a new world of microorganisms was discovered, such as minute Algae and Protozoa. In 1687, the Dutchman, Leeuwenhoek, discovered Bacteria. It was now asserted that the origin of living things was from minute organisms, which had arisen spontaneously. This idea persisted until the latter part of the nineteenth century. The methods of reproduction and life history of these forms were gradually ascertained and it was learned that dust, air and, in fact, all things contain spores of such organisms. These can *seed* any organic material left exposed to air, and the existence of hosts of such organisms is due to reproduction from parent organisms. Pasteur (Fig. 294) in 1860–64, by a series of most painstaking experiments, demonstrated the presence of microorganisms in air and on dishes. He also showed that some of these organisms (*anaerobic*) did not need free oxygen, but could get it by their own ability to decompose organic substances. His experiments constituted important disproof of Spontaneous Generation.

John Tyndall, the great English physicist, worked on optically pure air some time after this. He believed that such air, which contained no particles of any kind, would therefore, contain no microorganisms, and that if organic materials, which had been heated to such a temperature as to destroy all adhering living organisms, were exposed to such air, that then no life would appear in them. Tyndall's experiments, published in 1876, were convincing. It was proved that there was no spontaneous generation of life, and the age-long question was settled and today it is believed, as a general biological law, that so far as we know all living things come from living things.

But this does not imply that life has always existed. If the astronomer's hypothesis is correct that this globe was once a gaseous outcropping from the sun, no form of life known today could have then existed. It has been suggested, however, that life units could have come to the newly cooled earth from some other planet. However, it is not known that life exists on other planets nor does this explain the ultimate origin of life.

The chemist knows that water is a union of hydrogen and oxygen. Water has not always existed. It was *created* when hydrogen and oxygen united to form it. Neither hydrogen nor oxygen has the properties of water. Water is a thing by itself. Moreover, it is now believed on good evidence that not even the present elements, as we know them, have always existed, but that they have originated from preceding simpler things. So it is legitimate to suggest that living substance came into existence when the Earth was cooling — when there was atmosphere and water and when certain compounds of carbon, oxygen, hydrogen, nitrogen and sulphur, etc., were brought together in a certain way. Just as oxygen and hydrogen existed (as in the sun today) before water, and as water is something new and not at all the same as oxygen and hydrogen, so living substance is not merely oxygen-hydrogen-carbon and nitrogen, even if these existed prior to the formation of living substance. Life is a peculiar phenomenon in itself and protoplasm is the unique medium in which it finds expression. All notions as to the primal origin of life are speculations. That protoplasm arose spontaneously long ago is good speculation.

Germ Plasm and Somatoplasm. As a rule, animals reproducing sexually begin life as a single cell, the zygote, formed by the union of a spermatozoon and an egg produced respectively by a male and a female animal. Sperm are formed by a special gland or gonad called the testis and eggs by another type of gonad, the ovary. The tissues and organs of metabolism and adjustment cannot produce gametes. The protoplasm of gametes is unique in that the zygote cell formed by the union of a male and female gamete can form a new individual. None of the other specialized cells possesses this property.

FIG. 295. — August Weismann. Courtesy of Charles Scribner's Sons.

Facts such as these led Weismann (Fig. 295) to develop a theory set forth in his book entitled "The Germ Plasm," published in 1885. Some of the conclusions he maintains are these, although the evidence cited in support was not necessarily given by him: First: The protoplasm of gametes and of gamete-forming cells of gonads is different from that of other cells of the body, being denoted by the name *germ plasm* for the former and *somatoplasm* for the tissue cells. Second: Early in development (Fig. 296) germ plasm tissue is set apart from the body tissue or somatoplasm. Third: Somatic tissue may be modified by varying external and internal stimuli, but germ plasm remains unchanged throughout changes in environment; a great body of evidence supports this view. Fourth: Although Protozoa possess physical immortality because they reproduce by fission, which results in unbroken continuity of protoplasm from generation to generation; yet the greater part of the body (somatoplasm) of a metazoan animal dies at the end of life's span while its germ plasm is immortal, *i.e.*, continues life in the person of the offspring. Among the Metazoa, germ plasm is the living bridge which ever continues from generation to generation. Fifth: The germ plasm of the egg is not exactly like that of the sperm and neither are entirely representative of the individuals which produced them, so that *fertilization, in forming a zygote, effects a new combination of characteristics not hitherto existing.* The union of different protoplasms in fertilization is called *amphimixis.* *The effect of sexual reproduction is to bring about variation.* The cytological details of germ-cell formation and observations in breeding experiments support this conclusion. Asexual reproduction, on the other hand, effects the continuance of the same type of protoplasmic complex. If a form produced by asexual reproduction differs from its parent, the cause of the variation must be sought for in a different set of environmental conditions to which the offspring was subjected.

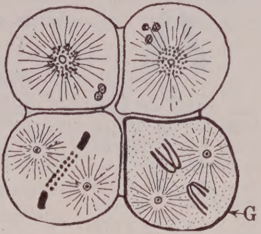

FIG. 296.—Four-cell stage in development of Ascaris. The cell marked 'G' will develop the germ-cell forming tissue while the rest of the body will be formed from the other three cells. From Conklin (after Boveri): *Heredity and Environment*, Princeton University Press. Reprinted by permission.

Germ-Cell Formation. The development of germ cells from gonads has been studied cytologically and these studies reveal many different kinds of changes, many of which concern the chromosomes. The student will be aided in understanding the processes of germ-cell formation if it is kept in mind that studies in the allied field of genetics indicate that chromosomes are made up chiefly of many ultramicroscopic multimolecular bodies called *genes*, probably protein in composition. Each gene is a determiner of a special characteristic that will appear in the developed individual. If, as stated above, germ-cell formation involves chiefly distribution of chromosomes and if the latter are composed of genes, it follows therefore that germ-cell formation is vitally related to problems of heredity.

The cytological changes involved in the production of spermatozoa from undifferentiated cells in the testis are denoted by the term *spermatogenesis*. The changes taking place in the production of ova from an ovary are denoted by the term *oogenesis*. These will be considered separately.

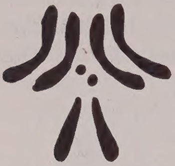

FIG. 297. — The four pairs of chromosomes of Drosophila (after Bridges). From Morgan: *Critique of the Theory of Evolution*. Princeton University Press. Reprinted by permission.

Diploid and Haploid Chromosome Numbers. Every individual is in a sense a duality. We already know that every cell in the body contains chromosomes. These, however, occur in pairs. Human body cells contain 48 individual chromosomes, *i.e.*, 24 pairs. As a rule, each pair of chromosomes has a distinct size and form, but both members of any one pair are similar in form (Fig. 297). One member of each pair was descended from a similar chromosome of the spermatozoan, and its mate in the same pair from a like chromosome in the ovum, when the individual was only a zygote, *i.e.*, a newly fertilized egg. Let us say that a sperm containing chromosomes a, b, c fertilized an egg containing chromosomes a', b' and c'. The zygote contains chromosomes a, a'; b, b'; c, c'. By a series of mitoses, in development the zygote becomes a sexually mature individual, every one of whose cells contain chromosomes a, a'; b, b'; c, c'. Each of these chromosomes is divided at every cell division in the life of the animal into two daughter chromosomes and daughter cells will always contain a similar set of chromosomes, a, a'; b, b'; c, c'. But as indicated above, this individual was derived from two sex cells, one contributing chro-

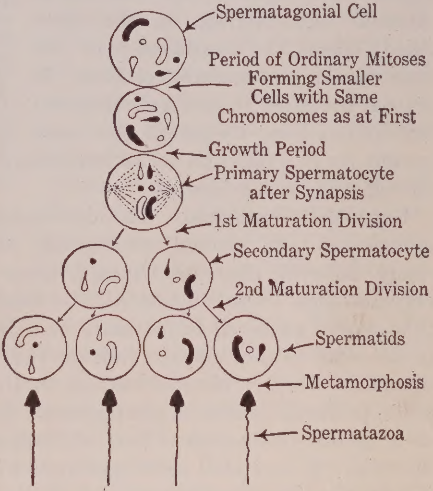
Spermatagonial Cell
Period of Ordinary Mitoses Forming Smaller Cells with Same Chromosomes as at First
Growth Period
Primary Spermatocyte after Synapsis
1st Maturation Division
Secondary Spermatocyte
2nd Maturation Division
Spermatids
Metamorphosis
Spermatazoa

FIG. 298 *A*. — Diagram illustrating spermatogenesis. Compare with Figure 298 *B*.

mosomes *a*, *b*, *c* and the other *a′*, *b′*, *c′*. We say that the cells of the body contain a *diploid* number of chromosomes and the sex cells the *haploid* number.

Spermatogenesis (Figs. 298 *A* and *B*). Let us ascertain how sperm are formed. Each spermatogonial or primary testis cell contains, for example, chromosomes *a*, *a′*; *b*, *b′*; *c*, *c′*. These cells undergo rapidly a series of mitoses, forming small cells each of which will also exhibit chromosomes *a*, *a′*; *b*, *b′*; *c*, *c′*, each time a mitotic spindle is formed. After this *period* of *rapid multiplication*, the cells stop dividing and undergo a *period* of *growth;* that is, they increase in size, forming *primary spermatocytes*, in which a mitotic spindle is later formed. In this, the chromosomes have united or paired off thus: *a-a′*; *b-b′*; *c-c′*; homologous chromosomes have lined up alongside each other.[1] If we regard *a*, *b*, *c* as *male* in the sense of being derived by descent from the male parent, and *a′*, *b′*, *c′* as female in a similar sense, then in the above pairing off, similar male and female members of the pairs associate in this union called *synapsis*. Synapsis is the first step in the final processes of maturation stages of spermatogenesis. After synapsis, the first maturation mitotic division occurs. When the two daughter cells called *secondary spermatocytes* are formed, each receives one member of each pair of chromosomes. For example, if one cell receives *a*, *b*, *c*, the other must receive *a′*, *b′*, *c′*. A second possibility is that one cell

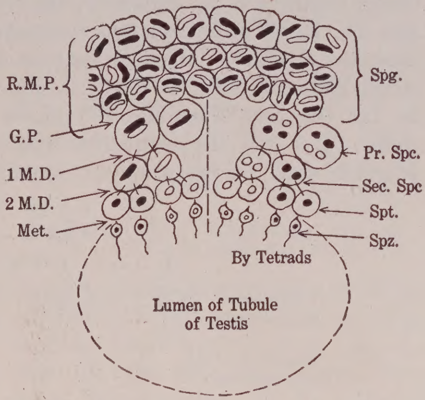

FIG. 298 *B*. — In this diagram a segment of a tubule of the testis is indicated. Outer row of cells are spermatogonia, *i.e.*, primordial germ cells. On the left are indicated: R. M. P., Period of rapid multiplication; G. P., Growth period; 1 M. D., 1st Maturation division; 2 M. D., 2nd Maturation division; Met., Metamorphosis. On the right are indicated: Spg., Spermatogonia; Pr. Spc., Primary spermatocytes; Sec. Spc., Secondary spermatocytes; Spt., Spermatids; Spz., Spermatozoa. Sometimes in synapsis, the double chromosomes appear in fours, *i.e.*, as *tetrads*, as shown at right of dotted line.

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[1] See Allelomorphs, Chapter XXIV.

receives *a*, *b*, *c′* and the other *a′*, *b′*, *c*. Eight different possible combinations are shown in Fig. 299. Immediately after the first maturation division, there follows the second maturation division, in which the chromosomes of the secondary spermatocytes are divided as in ordinary mitosis, each forming two cells (four in all) called spermatids. If one secondary spermatocyte possessed chromosomes *a*, *b*, *c*, then each of its two spermatids will possess chromosomes *a*, *b*, *c*. Similarly, the other secondary spermatocyte (*a′*, *b′*, *c′*) will form two spermatids each containing chromosomes *a′*, *b′*, *c′* or the four spermatids will have the following chromosome formula: 1. *a-b-c*; 2. *a-b-c*; 3. *a′-b′-c′*; 4. *a′*, *b′*, *c′*. So far the cells resemble the original spermatogonial cells in shape. But now the spermatids undergo a process of *metamorphosis* in which polygonal-shaped spermatid cells become modified into *spermatozoa*, each with a head, middle piece and tail (Fig. 302). The head is almost entirely concentrated nucleus surrounded by a thin film of cytoplasm. Indeed, the head is principally chromosomes *a-b-c*, for example. The middle piece contains a small amount of cytoplasm containing a centrosome in some cases. The tail is a long, vibratile, cytoplasmic thread. The motile sperm are liberated into the lumen of the gland ducts. Two things of importance are to be noted: First: As a result of spermatogenesis, sperm contain only half the number of chromosomes characteristic of the species, *i.e.*, the diploid number has been reduced to the haploid number and the reduction occurred in the first maturation division. In some cases the first division is an ordinary mitosis and the second is the reduction. Second: Different kinds of sperm are formed. In this particular instance, one is represented by the letters *a*, *b*, *c* and another by *a′*, *b′*, *c′*. But there might have been other types (Fig. 299), all depending on how they lined up in the equatorial

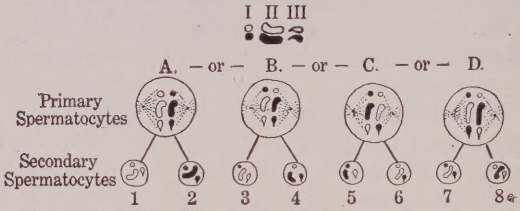

FIG. 299. — Illustrating eight different combinations of chromosome distribution when the primordial germ cells have three pairs of chromosomes.

place of the mitotic spindle of the first maturation division. Possible variations are represented: a, b, c; a', b, c; a, b', c; a, b, c'; a', b', c; a, b', c'; a', b, c'; a', b', c'.

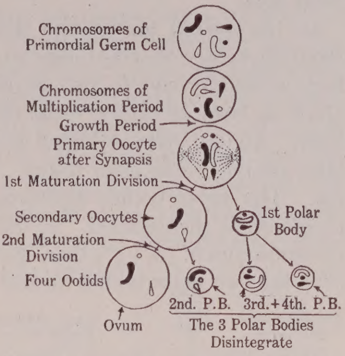
Chromosomes of Primordial Germ Cell
Chromosomes of Multiplication Period
Growth Period
Primary Oocyte after Synapsis
1st Maturation Division
Secondary Oocytes
1st Polar Body
2nd Maturation Division
Four Ootids
Ovum
2nd. P.B.
3rd.+4th. P.B.
The 3 Polar Bodies Disintegrate

FIG. 300 *A*. — Illustrating oogenesis. Compare with Fig. 300 *B*.

Oogenesis (Figs. 300 *A* and *B*). Development of ova from the ovary is fundamentally similar to that of the sperm, but it will be evident that growth is greater in the case of the oocyte than in the formation of spermatocytes.

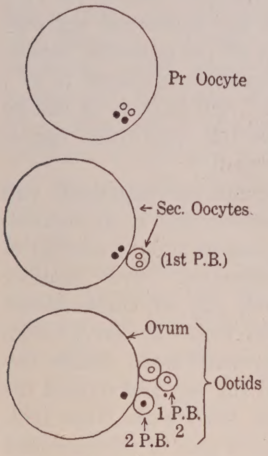
Pr Oocyte
Sec. Oocytes
(1st P.B.)
Ovum
Ootids
1 P.B.
2
2 P.B.

FIG. 300 *B*. — Oogenesis. In this diagram the size relations of polar bodies to ovum are indicated. The polar bodies are actually very much smaller.

There is a period of rapid multiplication of oogonia, resulting in the formation of *primary oocytes*. When the mitotic spindle for the first maturation division is formed, homologous chromosomes which were hitherto separated in all previous mitoses have now paired off in *synapsis*, making *half* as many *pairs* as there were single chromosomes. If the (diploid) chromosomes of the oogonia (and all other body cells) were a'', b'', c'', a''', b''', c''', then at synapsis they would be arranged thus: a''-a'''; b''-b'''; c''-c'''. The first maturation division (reduction) forms two cells. If one has received chromosomes a'', b'', c'', then the other must receive a''', b''', c'''. But as in the case of spermatogenesis there are other possible distributions, depending on how the synaptic pairs were arranged in the equatorial plane. For example, the distribution might have been a'', b''', c'' and a''', b'', c'''. The two cells formed are called *secondary oocytes*. These are not similar in size as are the secondary spermatocytes. One of the oocytes is *very small* although the nuclei of both are similar and contain the same number of chromosomes. The *small* secondary oocyte with a minimum of cytoplasm is called the *first polar body*.

In the second maturation division, the first polar body (the *small* secondary oocyte) forms *two* very small polar bodies while the *large* secondary oocyte also divides into two cells, one of which is about as large as before, while the other is a *third* very small *polar body*. All four cells are called *ootids*. Only *one* is *large;* the other *three* are *very small polar bodies*. The large ootid is the functional *egg*. The polar bodies *degenerate*. It is important to note the chromosome distribution. If the large secondary oocyte contains chromosomes a'', b'', c'', then the first polar body contains a''', b''', c'''; the two polar bodies formed from the latter will each contain similar chromosomes. But all the polar bodies degenerate and if, as stated above, their chromosomes contain potential hereditary qualities different in some respects from a'', b'', c'', which the functional egg possesses, all the potential hereditary qualities peculiar to a''', b''', c''' will have been lost so far as this particular egg is concerned.

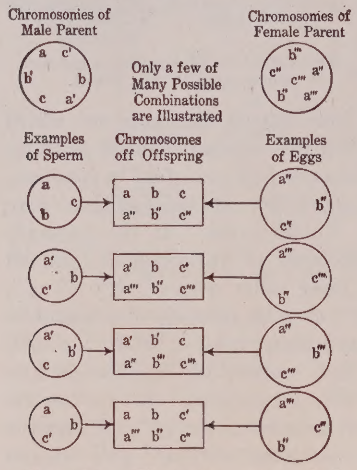
Chromosomes of Male Parent
a c' b' b c a'
Only a few of Many Possible Combinations are Illustrated
Chromosomes of Female Parent
b''' c'' c''' a'' b'' a'''
Examples of Sperm
Chromosomes off Offspring
Examples of Eggs
a c b
a b c a'' b'' c''
a'' b'' c''
a' b c'
a' b c' a''' b'' c'''
a''' c''' b''
a' b' c
a' b' c a'' b''' c'''
a'' b''' c'''
a b c'
a b c' a''' b'' c''
a''' c'' b''

FIG. 301. — Illustrating some of the different chromosome combinations in offspring of the same parents. The reader can discover other combinations. Compare with Fig. 299.

Oogonia, spermatogonia and all somatic cells of an individual possess a diploid number of chromosomes. One member of each pair of chromosomes of these cells was derived from the spermatozoan which fertilized the egg and formed the zygote, from which that individual developed. The other halves of each pair of chromosomes of the zygote were derived from the mother, *i.e.*, from the egg fertilized by that sperm. During all the thousands of mitoses occurring in development and during later life of this individual, these maternal and paternal chromosomes retain their original identity. During spermatogenesis and oogenesis, they pair off and one member of each pair is distributed to different germ cells. This results in a reduction of the diploid number to the haploid number and also brings about the probability of a new combination of chromosomes in the succeeding fertilization. In the accompanying chart, Fig. 301, a few illustrations are given to illustrate how this can happen. Neither spermatozoan nor egg contains *all* the hereditary material of their respective originators. It appears that the function of *sexual* reproduction is to produce individuals *different* in some respects from their parents. The new individual *may be* better adapted to life conditions than were the parents. Sexual reproduction by sperm and egg, produced by spermatogenesis and oogenesis, accounts in part for variations in plants and animals. Not all details of spermatogenesis and oogenesis are identical with the type illustrated above, but the end results are similar.[1]

Egg and Sperm. The egg cell is highly specialized. It contains the machinery for cell division; from it many differentiated cells will form in development; it will develop a specific organism, *i.e.*, a starfish egg will produce a starfish, a frog's egg will produce a frog and each of a particular species. Most eggs contain a substance which when oxidized furnishes the energy for the early stages in development. The various kinds of eggs with regard to distribution of yolk and relative quantities of yolk will be presently considered. Compared with the sperm, the egg is large, passive and yolk-burdened.

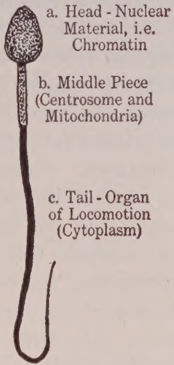
a. Head - Nuclear Material, i.e. Chromatin
b. Middle Piece (Centrosome and Mitochondria)
c. Tail - Organ of Locomotion (Cytoplasm)

FIG. 302. — Diagram of a human spermatozoan. It is 50–60 μ long. From Jordan (after Meves), *Textbook of Histology*, copyright 1927, by D. Appleton & Co. Reprinted by permission.

Although there are many varieties, a *typical* sperm (Fig. 302) has three parts: (*a*) Head — this contains but little cytoplasm, it is almost all nucleus, *i.e.*, compact chromatin. (*b*) A middle piece, supposed to contain a centrosome. (*c*) A long undulating cytoplasmic tail, a locomotor organ. The sperm resembles a flagellate Protozoan. Both sperm and egg agree in the possession of a chromosome equipment and the chromosomes of the sperm are in a sense mates of those of the egg.

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[1] In plants, the cells of the sporophyte have the *diploid* chromosome number. Reduction takes place in the first division in the spore mother cell so that spores (pollen grains and embryo sacs) gametes and the cells of gametophytes have the *haploid* number.

Fertilization. If sperm and eggs are deposited in water near each other, fertilization will occur there. If copulation takes place, then the spermatic fluid produced by the male reproductive system serves as the liquid medium in which the sperm may move toward the eggs. Sperm may enter the egg before oogenesis is complete or afterward. If the egg has a thin membrane, a sperm may perforate it and enter. A fertilization membrane, then formed, usually prevents the entrance of other sperm. In some cases the sperm is drawn into the egg from its surface. Only the head and middle piece of the sperm usually enter the egg.

Sperm contain only a limited amount of energy, but sufficient to bring them into contact with the egg. Fertilization does not occur in strongly acid or alkaline media. Activity of sperm takes place in the hydrogen-ion concentration of sea water or in water slightly more alkaline. Sperm are probably chemically attracted towards eggs. The physico-chemical system of the egg is somewhat analogous to a wound-up clock which is not going. Some substance in the egg inhibits the " starting up " of developmental processes. Something in the sperm overcomes this inhibition. It is said that anything that will cause the formation of an egg membrane will induce cell-division. F. R. Lillie's studies led him to conclude that the egg is an irritable physico-chemical system containing a definite substance called fertilizin, which, when free to act, starts up the machinery of development. The sperm has some substance which combines with fertilizin, overcoming its inertia and thus releasing it in an active condition.

When the sperm nucleus enters the egg, it is small but absorbs from the surrounding medium and increases in size. It moves toward the egg nucleus which, in turn, may move toward the sperm nucleus. The two appear to fuse, forming one nucleus, the zygote nucleus. The first cleavage is in the plane of the copulation path taken by the sperm nucleus in approaching the egg nucleus. It has been shown that, in many cases, the middle piece of the sperm contains a centrosome which will move ahead of the sperm nucleus and organize the first mitotic spindle initiating the first cleavage. In other cases this centrosome is formed in the egg and stimulated by the presence of the sperm nucleus. In the equatorial plane of this mitotic spindle appear the paternal chromosomes, introduced with the sperm, for example, " *a*, *b*, *c*," *and* the maternal chromosomes of the egg, *i.e.*, " a'', b'', c''." These will divide *individually* every time cell division occurs, but they do not *pair off* or undergo synapsis and later segregate to separate cells until the mitotic spindle of the first maturation division is formed at the time when this zygote has become a sexually mature individual. Note that the haploid number of chromosomes, characteristic of sex cells, is restored on fertilization to the diploid number which zygotes and their resulting cells possess.

Differences in Eggs as to Yolk Content. The presence and distribution of yolk varies greatly. In some eggs, there is a minimum of yolk and the cytoplasm is quite evenly distributed throughout. Most Coelenterates, Echinoderms, some Mollusks, Annelids, Amphioxus and the higher Mammals have eggs of this type.

In other eggs there is a greater accumulation of yolk at one end and it thins out toward the other end which is richer in cytoplasm. Two types are distinguished. In eggs like those of the frog, for example, there is no sharp line of demarcation between the cytoplasm and yolk, but they grade into one another. But in other eggs, like those of fishes, reptiles and birds, the egg cytoplasm containing the nucleus is in the form of a small disc-like mass at one end, sharply marked off from the great mass of yolk toward the other end.

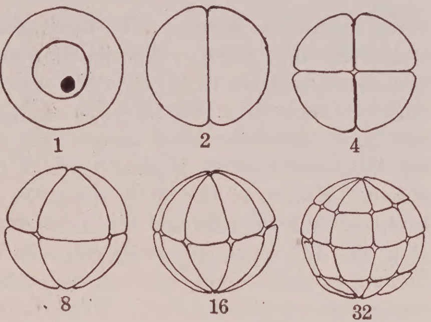


FIG. 303. — Cleavage in an Equal Holoblastic Egg. One, two, four, eight, sixteen and the thirty two cell stages are indicated.

Cleavage. The fertilized egg or zygote at once divides into two cells, thus initiating cleavage. Growth, differentiation and development of tissues and organs involve cell division by mitosis. But the word cleavage refers to early stage of cell formation in which the cells are increasing in number. The first cleavage plane passes through the *copulation path* taken by the sperm and egg nuclei as they unite in fertilization. In many cases it appears that the first cleavage plane establishes bilateral symmetry, *i.e.*, one of the first two cells forms the right side of the body and the other, the left side. Moreover it also appears the head will form from one end of these cells and the posterior part of the body from the posterior portion of the two cells. The egg divides (Fig. 303) into 2, 4, 8, 16, 32, etc., cells which become smaller and smaller as there is no absorption of material from without. The presence of yolk modifies the type of cleavage.

Types of Cleavage. Four chief types of cleavage are found among animal eggs.

A. Holoblastic. In this type of cleavage, the *entire egg* is divided into cells. But there are two types:

1. *Equal Holoblastic* (Fig. 304 *A*). In eggs, with little and diffuse yolk, as those of the star-fish and Amphioxus, the first cleavage plane takes place as indicated in the preceding paragraph and bisects the egg (Fig. 303–2). The second cleavage plane is at right angles to the first, and is also meridional, forming four equal cells (Fig. 303–4). The third plane is equatorial, forming eight cells (Fig. 303–8). The fourth and fifth cleavage planes are meridional and are in between the first and second and at right angles to each other (Fig. 303–16). This makes eight cells above and eight below the third plane. The sixth plane is parallel to the third and between it and the upper pole, making sixteen cells above. Almost at the same time, the seventh plane comes in between the lower pole and the equatorial plane and parallel to it (Fig. 303–32). This makes sixteen cells below or thirty-two in all. Cleavage planes rapidly succeed each other now and the geometric regularity is gradually lost. All the cells are of about the same size and so this type of cleavage is called Equal Holoblastic.

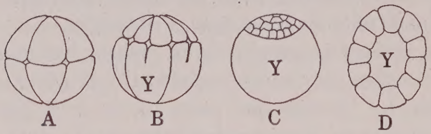


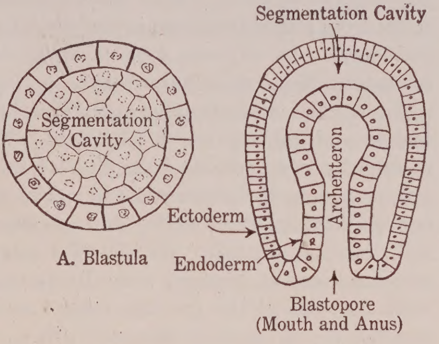
FIG. 304. — Types of cleavage. *A*, Equal Holoblastic — starfish; *B*, Unequal Holoblastic — frog; *C*, Discoidal Meroblastic — chick; *D*, Superficial Meroblastic — insect. (*Y*, yolk).

2. *Unequal Holoblastic* (Fig. 304 *B*). Such an egg divides completely, but the resulting cells are unequal in size. At the time when the first equatorial plane forms, there are four small cells above and four larger cells below. Then eight cells are formed at the animal or cytoplasmic pole above, before the larger four lower yolk laden cells have divided. The greater amount of yolk here seems to delay segmentation. This type of division is found in some Sponges, some Coelenterates, some Worms, Mollusks, in Petromyzon, some Fishes and in Amphibia.

B. Meroblastic or Incomplete Cleavage. In this type of cleavage, the yolk does not divide, but only the protoplasm. Two types are recognized as indicated by Fig. 304–*C* and *D*.

It is evident that no particular type of cleavage is related to the degree of specialization of the type of animal. It is more related to conditions under which development occurs. A mature adult results despite the differences in mode of cleavage. Very early in development and long before maturity the starfish and Amphioxus embryos become free-swimming and food-gathering. In those cases where much yolk is present, the simple type of cleavage becomes complex. In higher Mammals where placental feeding is resorted to, practically no yolk is needed. The early cleavage stages are very simple, but soon depart from this on account of the highly specialized structures that have to be developed in connection with embryonic nutrition.

In the following description of later developmental stages, only simple illustrations will be chosen. The student should be informed, however, that many embryological histories are far more complicated than these simple examples may appear to imply. Nevertheless, in spite of the differences in development, there is an underlying similarity making possible the science of embryology.



A. Blastula

B. Gastrula

Fig. 305. — *A*, Blastula; *B*, Gastrula.

Morula and Blastula. Cleavage soon produces a ball of cells in eggs with minimum yolk. This is called a *morula* and is best seen in this type of egg. As segmentation advances a cavity appears inside. This stage is called the *blastula* (Fig. 305 *A*). It is like a hollow ball whose wall is composed of one layer of cells. The cavity within is the *segmentation cavity*.

Gastrula (Fig. 305 *B*). Gastrulation is the process by which endoderm is formed. For example, the cells at one place in the blastula grow in by a process of *invagination* which is an infolding by growth so that what was an outer surface becomes an inner surface. It continues until the inturned cells form a blind sac, which in some cases is in contact with the outer cells. A two-layer double sac-like stage is produced. The inner layer of cells forms the *endoderm*. They may be a little larger than those of the outer *ectoderm* layer. The space, if any, between ectoderm and endoderm is still the segmentation cavity. The mouth is called the *blastopore*. The cavity within the endoderm is the *archenteron* or primitive gut. There are now two primary *germ layers*, ectoderm and endoderm. The ectoderm may be regarded as related to functions of *adjustment;* the endoderm, to functions of *metabolism*. A review of the anatomy of Coelenterates shows that they are but specialized gastrulae.

Origin of Mesoderm. The origin of the mesoderm is diverse. There is none in Porifera and Coelenterates. It first appears in Platyhelminthes and occurs in all higher phyla. Mesoderm may arise from primary mesoblast cells (mesoderm formers), appearing in the segmentation cavity and originating from endoderm as in the earthworm (Fig. 170). Mesoderm in different animals originates from either ectoderm or endoderm or both, but usually from endoderm. In any one type it always forms in the same way. Mesoderm develops in three ways.

First: The Enterocoelic type. This happens in many invertebrates and among lower Chordata. Mesodermal pouches are formed by evaginations from the lateral walls of the embryonic gut, beginning at the anterior end. The pouches enlarge, obliterating the segmentation cavity and are soon detached from the gut wall, thus forming sacs. With further enlargement, the enterocoelic pouches come in contact with the external ectoderm externally; with the wall of the gut internally; and the faces of successive pouches are in contact with each other. In the earthworm these transverse walls become the septa of the adult worm and the pouch cavities form the coelome. In many forms, however, these walls disintegrate, thus forming two continuous cavities on either side of the gut (endoderm) and inside the body wall (ectoderm). That portion adjacent to the ectoderm is called *somatic mesoderm* (Fig. 306) and that adjacent to the endoderm (gut) is called *splanchnic mesoderm*, the cavity between the two being known as the *coelome* or *body cavity*. While the above changes are going on, the enterocoels on either side of the gut have enlarged until they meet ventrally underneath the gut, where their adjacent walls form a vertical sheet of tissue connecting the lower midline of the gut to the ventral midline of the body wall. This sheet of supporting tissue is known as a mesentery. It remains in many Invertebrates, but in the Vertebrate soon disappears. Thus in the latter, one continuous coelome is formed. In a somewhat similar way a dorsal mesentery is formed which remains throughout life in the Vertebrate, connecting the intestinal tract to the dorsal midline of the body cavity and acting as a suspensory medium.

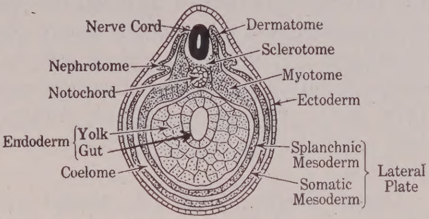


FIG. 306. — Diagram of cross-section of young amphibian embryo.

Second: Mesoderm also originates by the splitting off of a layer of cells from the endoderm along the dorsal midline of the embryo. This is known as *delamination.* The delaminated layer splits later into somatic and splanchnic mesodermal sheets and coelome as before.

Third: In most of the higher Vertebrates mesoderm originates from the undifferentiated tissue where endoderm and ectoderm fuse along the dorsal midline of the embryo, these eventually forming the somatic and splanchnic layers as before, with the coelome between.

The Fate of the Germ Layers. Each of the germ layers, ectoderm, mesoderm and endoderm, develop quite uniformly into particular adult structures.

(*a*) Ectoderm forms the epidermis of the skin, skin glands, hair, feathers, nails, hoofs, lining membrane of the mouth and anus, parts of the eye and ear and the nervous system.

(*b*) Mesoderm develops into the soft connective tissues, cartilage, bone, skeletal muscles, heart, blood vessels, blood, most of the urinogenital system and the connective tissue and involuntary muscle of the alimentary tract.

(*c*) Endoderm forms the lining (mucous) membrane of the gastro-intestinal tract, the multitudes of small glands in this tract and the larger glands such as the pancreas and liver, the lining of the respiratory system, the glandular portions of the thyroid and thymus glands.

Notochord. In Amphioxus (Fig. 227) a linear group of cells along the dorsal midline of the embryonic gut (endoderm) develops into the notochord, which later becomes separated from the gut and extends the length of the body above the gut. In Vertebrates the notochord is formed in much the same way. The possession or formation of a notochord is one of the unifying features of the Chordates. It is a firm rod of soft cells, which in most Vertebrates is but a temporary structure existing during development (Fig. 307). It soon disappears, being replaced first by a cartilage and later by bone (backbone), in animals that have a bony skeleton.

Dorsal Nerve Cord. A second common characteristic of Chordata is the embryonic nerve cord, which develops into the central and peripheral nervous system. It is located above the notochord and above the gut, quite the opposite of its position in Annelids and Arthropods.

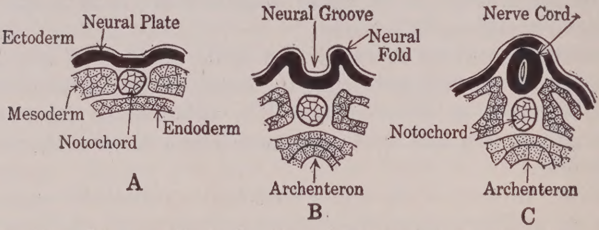


FIG. 307. — Diagrams illustrating formation of central nervous system.

In the frog embryo, about the time the gastrula is formed, the ectoderm forms two or more layers of cells. Along the dorsal surface the ectoderm thickens, forming the *neural plate* (Fig. 307 *A*), which extends forward into a wide, rounded front portion. Then the margins of the plate thicken to form lateral neural folds between which is a depression, the *neural groove* (Fig. 307 *B*). The neural folds grow higher, the groove deeper and the folds grow toward each other and join, forming the neural tube (Fig. 307 *C*), which is beneath the outer ectoderm. The anterior enlarged portion of the neural tube develops into the brain, while the more slender posterior portion becomes the spinal cord. The peripheral nerves develop from cells in the neural tube.

Developing Mesoderm (Fig. 306). The mesoderm described above gradually develops into three well-defined masses of cells.

First: The first of these is called the Lateral Plate and consists of the greater part of the somatic and splanchnic mesoderm with the coelome between.

Second: A mass of mesoderm cells on either side of the nerve cord and notochord in the dorsal-median portion of the embryo forms a long strip of tissue called the *segmental plate.* This increases in thickness. By a series of transverse divisions, beginning in front, the segmental plate is cut (by growth) into a succession of blocks of tissue called *somites.* In cleared preparations of embryos these can easily be seen. Their number is an index of the age of an embryo. They are homologous with the somites of the earthworm and the myotomes of Amphioxus and appear in embryos no matter whether mesoderm is formed by enterocoelic pouches, delamination or proliferation. They are considered as one of the characteristics joining Chordata to organic relationship with Annelids.

Each somite develops three special regions: (*a*) The *dermatome.* This is thin and lies laterally just beneath the adjacent ectoderm. It develops chiefly into the dermis of the skin. (*b*) *Myotome.* This portion is thicker and medial to the dermatome. It is the chief originator of the voluntary muscles. (*c*) *Sclerotome.* This is a mass of loose cells between the myotome and the notochord. From this mass of cells the axial skeleton is formed.

Third: There remains a small mass of cells in the upper lateral part of the body cavity between the lateral plate and the somites. This mesodermal tissue is called the *nephrotome.* From it will develop the greater part of the excretory system.

The somatic mesoderm of the lateral plate forms the outer wall of the pericardium, pleurae, and peritoneum; while the splanchnic layer forms the heart, inner wall of the pericardium, pleurae and the mesenteries, and connective and involuntary muscle tissues of the gastro-intestinal tract.

Further Developmental Stages. As gastrulation, in the *frog,* continues, the body lengthens, a permanent antero-posterior and dorso-ventral differentiation is established and the embryo is bilaterally symmetrical (Fig. 308). Externally the head region and body regions are outlined. On the antero-ventral surface of the head appears a pair of slight outgrowths marking the position of the optic cups forming from the brain within; to the side and below these, a pair of nasal pits later to form part of the nasal passages; on the lateral surfaces of the head are shown ridges marking the developing gill arches between which are grooves where the future gill slits will appear. A pit develops from invagination at the posterior end of the embryo, below the blastopore. The latter closes, while the invagination continues until the passageway is connected with the hinder part of the embryonic gut. This newly formed passageway is the *proctodaeum* and its external opening is the *anus*. Similarly a pit, originating by invagination of ectoderm, forms on the front ventral surface of the head. This continues until it connects with the blind front end of the embryonic gut, forming the *stomodaeum* and its *anterior opening* is the *mouth*.

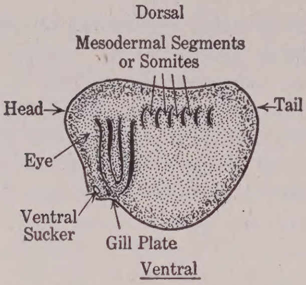


FIG. 308. — Young frog embryo. From Curtis and Guthrie, *Textbook of General Zoology*, copyright 1927, John Wiley & Sons. Reprinted by permission.

External gills which are small tufted processes grow out from the gill plates before hatching and are functional for a time after hatching. Blood from the newly formed heart is pumped out to capillaries in these gills, and after aeration the blood passes back to a dorsal aorta to be circulated throughout the body. The external gills are soon replaced by so-called internal gills bordering on gill slits which have formed in the wall of the pharynx between the gill arches. The embryonic circulation is shifted to these new gills. Both gills and the circulatory system involving them are similar in many ways to those of fishes.

The different regions of the intestinal tract gradually differentiate (Fig. 309). Evagination of a solid mass of cells in the floor of the back part of the pharynx is the first indication of the future trachea and lungs. Similarly the liver begins as a proliferating mass of cells from the floor of the fore-gut. The first part originating from the gut becomes the bile duct. Nearby develops the pancreas. From the floor of the posterior region of the intestine develops the cloacal bladder. Proliferations of cells from the first and second pair of gill clefts form a mass of cells destined to become the thymus gland. On the floor of the pharynx back of the glottis, in the midline, a rod-like mass of cells is formed which later develops into the thyroid.

The anterior enlarging end of the neural tube has by constrictions formed the three embryonic regions of the brain (Fig. 309), namely, the *fore*, *mid* and *hind* brain. From the fore brain develops the prosencephalon or cerebral hemispheres, and the diencephalon, to which the pituitary gland is connected. The mid brain develops into the mesencephalon which bears the optic lobes, while the hind brain develops into the metencephalon or cerebellum and the myelencephalon or medulla.

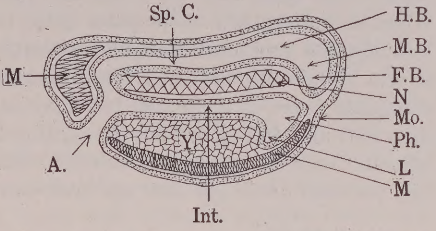


Fig. 309. — Longitudinal vertical section of early frog embryo. *Sp. C.*, spinal cord; *H.B.*, hind brain; *M.B.*, mid brain; *F.B.*, fore brain; *N*, notochord; *Mo.*, mouth; *Ph.*, pharynx; *L*, liver; *M*, mesoderm; *Int.*, intestine; *Y*, yolk; *A*, anus.

From each of the sides of the fore brain an evagination forms a saccular outgrowth, the optic vesicle (Fig. 310). As development proceeds these are connected to the brain by optic stalks. When the optic vesicles reach the external ectoderm, a thickening appears there. The outer wall of the optic vesicle just opposite this new thickening now invaginates, forming a double-walled optic cup. The thickening just spoken of later forms the lens of the eye. The inner inturned wall of the optic cup develops into the retina. The outer wall of the cup forms the pigmented layer behind the retina of the adult eye. The rods and cones, sensory cells of the retina, are connected with special nerve cells which, forming here, grow toward the brain along the optic stalk and so form the optic nerve. The choroid coat of the eyeball outside the retina and the sclerotic coat outside the choroid are both formed from wandering mesoderm cells.

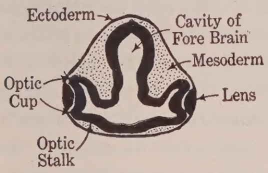


Fig. 310. — Section through head of amphibian embryo, showing development of eye.

Special attention has been called to the external and internal gills which the early frog embryo and tadpole develop. It is of interest to know that elasmobranch embryos develop external gills before their internal gills appear. The formation of gills involves also the special development of arteries and veins to connect the gills with the heart and central circulatory system. When metamorphosis takes place in the tadpole, and gills give way to lungs, this profound change necessitates a corresponding change in the circulatory system. The embryos of reptiles, birds and mammals never develop gills but they *do* develop gill arches, gill slits, and also the embryonic circulation for a time appears to be adjusted to a gill type of circulation although there are no gills. But the embryonic gill slits are evanescent structures as are also the early circulatory structures related to them.

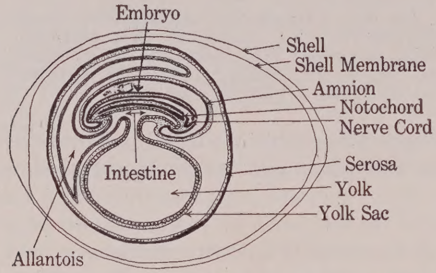


Fig. 311. — Chick embryo in shell showing relations of amnion, allantois and yolk sac to embryo. Modified from Arey (from Prentiss), *Developmental Anatomy*, W. B. Saunders Co., 1926.

Allantois and Amnion. In Reptiles and Birds, the embryo develops in a disc of cells on the yolk inside the white of the egg and its shell. An early indication of the embryo is a thickening in the middle of this disc. The development of organs occurs as before, but the periphery of the disc grows down around the yolk. The superficial layer of the disc is ectoderm lined with mesoderm, or somatopleure; while next to the yolk is splanchnopleure or splanchnic mesoderm and endoderm. Between the two is coelome. A fold of somatopleure (ectoderm and mesoderm) grows up in front of the head. Similar folds appear on each side of the embryo and behind. These folds grow up around the embryo and meet above it. They are double and, after they meet, the inner layers fuse with the inner layers and the outer layers fuse with the outer layers. The fusion of the inner layers forms a sac, the *amnion*, which incloses the embryo (Fig. 311). Above this is the *serosa*, formed by the fusion of the outer layers of somatopleure. The amnion sac is filled with a fluid bathing the embryo. Externally, the amnion and serosa are in contact unless prevented by presence of some other structure. The amniotic fluid protects the embryo from physical shocks when the egg is moved. The splanchnopleure grows around until it encloses the yolk, thus forming a yolk sac. This is connected with the embryonic gut.

As the amnion is growing, a sac called the *allantois* grows out from the floor of the hind gut. This is therefore composed of splanchnopleure. The allantois grows out between the amnion and serosa. In the allantoic walls develop veins and arteries which are in connection with the blood system of the embryo. The allantois is close to the porous shell and is a respiratory organ for the embryo. Oxygen enters through pores in the egg shell, and into the capillaries of the allantois and so to the embryo. In reverse fashion the CO_2 passes out. Wastes of later embryonic development collect in the allantois. The yolk in the yolk-sac is gradually absorbed. When the animal is ready to hatch, it bursts through the amnion, serosa and shell, and is parted from these now useless structures. The allantois is homologous with the cloacal bladder of Amphibia.

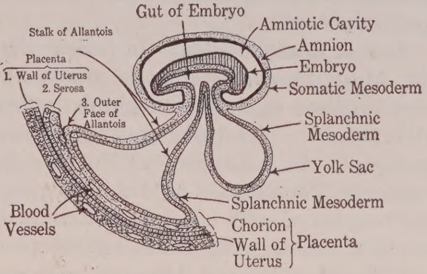

Gut of Embryo
Stalk of Allantois
Amniotic Cavity
Amnion
Embryo
Placenta
1. Wall of Uterus
2. Serosa
3. Outer Face of Allantois
Somatic Mesoderm
Splanchnic Mesoderm
Yolk Sac
Splanchnic Mesoderm
Blood Vessels
Chorion
Wall of Uterus
Placenta

FIG. 312. — Mid-sagittal section of foetal membranes and allantoic placenta of a mammalian embryo. Modified from Arey (from Prentiss), *Developmental Anatomy*, W. B. Saunders Co., 1926.

Placenta (Fig. 312). The placenta, as has been described, is a structure which vitally connects mammalian mother and offspring. It is formed by a union between a portion of the uterine wall and part of the chorion, which is a union between the serosa and the distal part of the allantois. The allantoic structures of *Sauropsida*[1] are retained and used in a new way, due to the absence of yolk and due to a superior method of rearing, which is wholly intrauterine.

In the mammal embryo, amnion and allantois are formed. The true amnion forms a sac filled with liquid in which the embryo lies protected. The outer face of the vascular allantois is in close connection with the inner face of part of the serosa and these two form the chorion, which is in contact with the wall of the uterus. Both uterine wall and chorion grow in thickness where they are in contact. The peripheral ends of uterine and foetal blood vessels become large sinuses where the uterine wall and chorion meet and develop the placenta. These foetal and maternal sinuses dovetail and interlock. The maternal blood is very near to the foetal blood. (See Fig. 270.) The umbilical cord connects the foetus with the placenta. It is covered with ectoderm and consists chiefly of a soft (mucous) tissue which supports the yolk stalk, the stalk of the allantois, two allantoic arteries and the large allantoic vein. There are different types of placentae. In the Primates (man) it is *discoidal*, or saucer-shaped, and is in intimate connection with uterine tissues. From the center of the inner face originates the umbilical cord.

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[1] Huxley combined reptiles and birds into the group, Sauropsida because they were so similar, anatomically.

Law of Recapitulation. In review it is important to note that: (*a*) Most sexually reproduced animals begin life as a *single cell*, the fertilized egg. This might be called the protozoan stage of development. (*b*) Early cleavage stages form a *morula*, a spherical group of cells. Associations like this are found in Protozoa, for example, Pandorina. (*c*) Later cleavage produces a *blastula*, a hollow ball of cells. Volvox is like this. (*d*) Later, the embryo forms a *gastrula*. Hydra and Coelenterates have this body plan. (*e*) Reptile, Bird and Mammal embryos have gill slits and gill arches and never use them. They are adult structures in Fishes and in some Amphibia.

It appears from this review that the higher animal in its development recapitulates its own ancestral history, presenting, as it were, a sort of synopsis of a few of the morphological stages passed through. Von Baer, in 1828–34, making a general and comparative study of the embryology of animals, concluded that early in development widely separated animals, such as Reptiles, Birds and Mammals, had so many characters in common that it was difficult to distinguish between them; and that development proceeded from a general to a special type.

Fritz Müller, in 1863, expressed the opinion that the embryological history of an animal indicated ancestral stages through which it passed. Haeckel in 1874, accepted and overemphasized this theory. It is known as the Recapitulation Theory or Biogenetic Law, *i.e.*, ontogeny recapitulates phylogeny; an animal in its development goes through stages which indicate its ancestors.

Starfish, earthworm, snail, Amphioxus, frog, reptile, bird and Mammal have a gastrula stage — which indicates that their ancestor was a coelenterate-like animal. The fact that they all start from a single cell means that the most primitive ancestor of all animals was a protozoan-like form. The formation of gill slits and other features in reptile, bird and mammal embryos show their fish-like ancestry. Though these phenomena are significant, yet some enthusiastic adherents of this theory went far afield to interpret all embryological structures in terms of the phylogenetic law. But embryological development is not *merely* the recapitulation of ancestral history. Three weeks elapse between the beginning of cleavage and the hatching of a chick. How could all the stages in the evolutionary development of birds be exhibited during such a brief embryological period? After a long period of research, inspired by the phylogenetic theory, embryologists gradually came to the conclusion that the application of the law was limited, although this does not mean that parallelism in development is without evolutionary significance.

Preformation and Epigenesis. It seems axiomatic to anyone who studies the embryology of an animal from the fertilized egg that a large and complex organism develops from an apparently simple microscopic mass of undifferentiated protoplasm. Charles Bonnet, who first discovered parthenogenesis in Aphids, philosophized deeply concerning development. He satisfied himself, at least, that, after all, there was no development, but that the egg contained in its small compass all the parts of the adult. Nothing new appeared, only the gradual unfolding of what preexisted took place. Thus there arose the embryological doctrine of *preformation*. Bonnet carried the idea to absurd limits. If the animal is preformed, an animal of the next generation is present in it in still smaller compass and so on ad infinitum. All thinking along embryological lines was dominated by this idea during the seventeenth and eighteenth centuries. It was even computed that Eve, the mother of all men, possessed 200,000 millions of homunculi (little men) in her ovary. Indeed, the preformation school divided into the *Ovists* and *Animalculists*. According to the former, the egg contained miniatures of future descendants. But spermatozoa had been discovered and so others (Animalculists) believed that the sperm alone functioned and that the eggs were only soil in which the organism resident in the sperm could develop.

Speculation followed speculation. In 1759, Wolff checked all this by conclusions based on painstaking observations on the development of the chicken, and published a paper called "*Theoria Generationis.*" He showed that the early embryo contained no future parts, but that the organs appeared gradually one after the other. From early simple substance, differentiation to later complexity took place. In other words, there was no mere unfolding of parts already formed. This is known as the *Doctrine of Epigenesis.* The zygote is a generalized cell capable of developing by a long series of mitoses, the differentiated tissues and special organs of the adult.

Prelocalization. Experiments carried on during the latter part of the nineteenth century demonstrated that not *preformation* but *prelocalization* is true of some eggs. For example, in the egg of Cynthia, a Tunicate, the cytoplasm of the egg shows five different zones or bands of protoplasm: first, clear; second, light gray; third, dark gray; fourth, light yellow; fifth, dark yellow. As development proceeds these are parceled out to definite groups of cells and organs. The clear protoplasm becomes *ectoderm;* the dark gray becomes *endoderm;* the yellow becomes *mesoderm.* If the egg is punctured and the clear substance removed, the embryo possesses no ectoderm and can produce no ectodermal structures. Of course, such an embryo does not mature. These experiments demonstrate a kind of prelocalization. Other eggs are not differentiated so early as the one-cell stage. This is known to be true of the eggs of the sea-urchin and Amphioxus. If such an egg is punctured and some of the cytoplasm is removed, a perfect embryo results. If in the two-cell stage one is destroyed or the two separated, perfect embryos result. Any cell of the 4- or 8-cell stage has the power of forming a perfect but smaller embryo. Sooner or later, but comparatively early, however, differentiation appears and after this stage, such fragments die. Indeed these experiments show the truth of both preformation and epigenesis, for they demonstrate the gradual development of the complex from the simple as well as showing prelocalization.

Identical Twins. The experiments also throw light on the origin of such twins. It is thought that the fertilized egg begins to develop normally but at an early stage separates into two growing centers, each of which develops into a perfect mature organism and both are remarkably alike. When one stops to consider the similarities in stature, figure, features, hair color, eye color and even mental characteristics of two identical human twins, each derived from half of a mere speck of protoplasm one is forced to conclude the generalized conditions of the germinal cell and the equal distribution in it of all its elements. Although there are definite indications of prelocalization of egg cytoplasm, yet a still more significant organization is present in the chromosomes and is discussed in the study of Genetics.

Abnormal Development. The course of development does not always run smoothly. Departure from normal environmental conditions modifies normal development. Possibly unusual chemical conditions change it. Abnormalities often appear. Organs are misplaced or incomplete, or lacking, or out of proportion, or doubled. One or both legs may be lacking or one or both arms or there may be more than four limbs.

Experimental Embryology. Experiments on eggs and embryos of lower forms throw light on these matters. If the developing limb bud of a frog is destroyed, no limb will develop because all the "limb-forming substance" is destroyed. Suppose the two-cell stage be partly separated. Then a two-headed and one-bodied embryo may develop, or one-headed and two-bodied or two-headed, one-bodied and two-tailed, depending upon how and where the cells are separated. All sorts of combinations have been produced. If a light weight such as a cover glass is placed on the developing egg of the starfish, for example, a flat plate of cells soon appears. If the weight is continued further, a very abnormal embryo is formed. In cold-blooded animals, it appears that if the temperature is lowered where eggs are developing, the developmental rate is slower and the same is much more rapid than usual if the temperature is raised. If eggs develop under conditions of extreme temperatures, abnormalities occur and of course death, if the temperature limits are further changed. By adding certain salts such as those of magnesium to sea-water in which eggs of marine fishes are developing, a variety of monstrosities result, as, for example, an animal with one eye, a cyclops, formed by the fusion of both optic vesicles.

If the two-cell stage in development is divided into the two component cells, each of the latter, in the case of certain animals, will develop into a perfect embryo. If the same experiment is performed on the eggs of other animals, imperfect half embryos develop. If a fertilized egg is divided into two pieces, so that one piece contains the nucleus and the other has no nucleus, both pieces may be fertilized and each will form an embryo. The first piece possesses the egg chromosomes ($\frac{1}{2}$) and to these are added those of the sperm ($\frac{1}{2}$), and in spite of the fact that only part of the usual cytoplasm is present, an embryo forms. But the other piece of the egg has *no* chromosomes and so in fertilization it has only one half the usual number, yet an embryo sometimes forms. It is found, however, that the later cells, *i.e.*, 2-, 4-, 8-, etc., each have the usual number. This is brought about in the following manner. A mitotic spindle forms in the fertilized enucleated piece, and the half chromosomes divide, forming the usual somatic number, but the cell does not divide. When it does divide, each of the first two cells and later ones receive the full complement of chromosomes.

Prenatal Influences. We shall later discuss the fundamental importance of heredity in determining what kind of an individual shall develop from a fertilized egg. We shall have occasion to point out evidences that indicate that the egg and sperm contain multi-molecular and ultra-microscopic bodies called genes which determine at the time of fertilization the characteristics that will appear when the zygote has developed. We are not concerned just now with arguments for or against Weismann's contention that environmental changes do not affect the germ plasm. The present day expression of Weismann's position would be as follows: Environmental conditions changing the body do not change the genes. This question aside, it is nevertheless true that the ever-varying external and internal environment does affect the developing zygote. The zygote may start with perfect genes, but conditions may appear during the embryological period that may distort the normal course of development of the genes.

Many people believe that abnormalities are directly due to prenatal mental influences; that shocking incidents so impress the mother as to affect the normal development of her child and mark it in some way. A common story is this: A pregnant mother was frightened and shocked at the sight of a mad dog biting a child on the arm. As a result her baby, when born, showed a red scar in a corresponding place. There is no scientific connection between the phenomena. Many babies have been born with scars on their arms, although their mothers never saw a mad dog. Mothers surrounded by the most favorable conditions during pregnancy have been known to give birth to abnormal offspring. Of course the abnormality must have had a cause, but the possibility of any specific effect of mental conditions of the above sort is highly improbable.

Telegony. Somewhat related to the popular notion of prenatal influence is belief in Telegony. Some animal breeders believe that breeding a pedigreed female to a low-grade male so affects the female that her *later* offspring, even though fathered by a *pedigreed* male, show taints of the former low-grade mating. There is no well-founded evidence for this belief. Understanding of the processes of reproduction involved, negatives the possibility of such an effect. The only vehicle by which the low-bred male could have affected the female was his spermatic fluid containing sperm cells. Neither remains potent for very long. They could not affect later matings. If a pair of pedigreed stock produce inferior offspring, it is far more likely that the inferiorities which appear are the outcroppings of inferiorities possessed by the ancestors of one or the other of the pedigreed parents. An explanation of reversions which are common occurrences is presented in the discussion of genetics.

Conclusion. Lured by the hope of finding ever more convincing evidences in proof of the Law of Recapitulation, embryologists of the last century worked out in accurate detail the embryology of a host of forms of animals. As limitations of the application of this law increased, scientists lost interest in this sort of research. However, the successive events in the development of animals representing every phylum had been satisfactorily recorded, but the accomplishment of this monumental task did not satisfy the new recruits. The description of what takes place, step by step, does not explain the process of development. What causes the orderly succession of increasingly complicated differentiation? What forces in the blastula cause the formation of the gastrula? Why should a minute speck of protoplasm which we call a human zygote develop into a human being? What is the nature of the marvelous organization of the egg that in the normal course of events produces such a result?

Turning from the earlier morphologically descriptive embryology, investigators attempted to discover the nature of the processes of development by resorting to experiments such as have been indicated above. When discordant results were obtained with different eggs, certain experimental embryologists decided that such work was futile. One of the most brilliant of these investigators, Driesch, went further than this. He concluded that the activities of the organism and of its cells and of cells at every stage in life were presided over, or governed, or directed by a mystical force or principle which he called " Entelechy," whose nature could not be ascertained by the tools or methods of physical science. This philosophy is called Vitalism. It stifles any progress in increasing our knowledge of the processes of life. On the other hand, many investigators, by using the tools and methods of physical science, have added a great deal to our understanding of the embryological problem.

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CHAPTER XX

HISTOLOGY

Introduction. Bichat in his " General Anatomy," published in 1801, pointed out that not only were structural similarities true of the organs of animals, but also of their tissues such as muscles and nerves. In 1838–39, Schleiden and Schwann advanced the analysis of organs when they announced the cell theory according to which the tissues of organs are composed of cells. In 1858, Virchow extended the application of the cell theory to diseased tissues.

Many individual Protozoa are single cells. Free single cells are also found in higher organisms. Examples are amoeboid white-blood cells, red-blood cells or erythrocytes, spermatazoa and ova. Colonial Protozoa are aggregations of similar cells which form a single organism. The Metazoa as a rule begin life as a single cell.

The gastrula stage in development establishes two principal embryonic tissues, namely, ectoderm and endoderm. The special tissues of Coelenterates consist of modifications of these two types of embryonic tissue. In our study of Hydra, we called attention, for example, to the (*a*) epithelio-muscular cell, (*b*) sensory cell, (*c*) nerve cell, and (*d*) cnidoblast cell — all of which are specialized, originating from simple embryonic ectoderm.

In the Platyhelminthes and higher Metazoa, a new embryonic tissue, the mesoderm, appears between the ectoderm and endoderm in the late gastrula stage. It is the purpose of the present chapter to present an account of the histological structure of the principal tissues of a vertebrate animal. It should be remembered that the tissues reviewed develop from the three primary germ layers as indicated. Histologists usually *classify* tissues, however, from a *physiological* rather than from an *embryological* point of view. We shall study tissues from the structural and functional point of view. Histologists divide the tissues of the body into five main types, namely, (*a*) Epithelium; (*b*) Connective; (*c*) Muscular; (*d*) Nerve; (*e*) Blood and Lymph.

A. Epithelium (Fig. 313 *A*). Some varieties of this tissue are similar to embryonic ectoderm and endoderm. It is derived, however, from all three embryonic tissues. Epithelium forms membranes covering the external surface of the body or forms a lining of cavities or tubes within the body. In Invertebrates the "skin," or epithelium covering the surface of the body, consists of one layer of cells. In the earthworm, these form a non-cellular external layer called the *cuticle.* In Mollusca, this epithelial layer secretes the *calcareous shell* and in Arthropoda, it forms the *chitinous* exoskeleton. The following types of epithelial cells occur in the Vertebrates but are not necessarily limited to them.

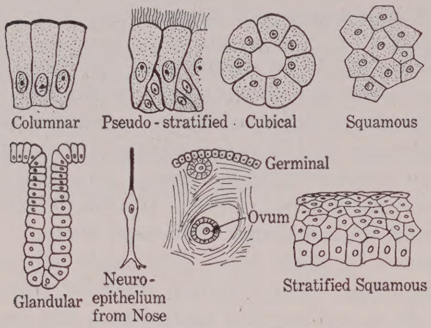

FIG. 313 *A*. — Types of epithelial cells.

1. *Columnar.* These cells are tall and columnar in shape. They are located side by side, forming one layer, the long axis of the cell being perpendicular to the surface of the membrane. This type of epithelium forms the lining of the stomach, small and large intestines. Absorption of digested food compounds by the columnar epithelium of the intestine is one of the functions of this epithelium.

2. *Cubical.* This cell is about as tall as it is wide and thick, or, in other words, it is cubical in shape. Portions of the tubules of the kidney and the vesicles of the thyroid gland and parts of the ducts of glands are composed of cubical cells.

3. *Squamous.* These cells are flat or scaly in form. The nucleus may appear as a slight bulge in the center of the flat cell. Squamous cells form the coelomic surface lining of the peritoneum and the exposed surface membranes of the mesentery and the lining membrane of the heart and blood vessels. These cells form the walls of capillaries and also the surface membrane on the outside of the digestive tract and are well adapted to the gentle movements of the viscera against one another since they are well lubri-

cated. In the blood vessels they are adapted to the smooth flowing of blood. They also form the walls of the air sacs of the lung, where they are adapted to diffusion of respiratory gases.

4. *Glandular.* In the intestinal tract, some of the columnar cells are specialized to form goblet-shaped accumulations of mucus which swell the cells. The secretion is discharged from the free surface into the lumen of the intestine. Such *goblet cells* are *unicellular* glands. On the other hand, the *glands* connected with the digestive tract are formed by evaginations of the intestinal endoderm during embryonic development. These glands vary in complexity from simple to compound types. In the mucous membrane of the small and large intestine are simple tubular glands; in the skin of the frog are simple alveolar glands; in the mucous membrane of the stomach the simple tubular excretory ducts receive secretions from several glandular branches. The kidney is an exceedingly complex compound-tubular gland as are also the salivary glands and pancreas. The mammary gland and the lungs are compound alveolar glands. The secreting cells of many glands are *polyhedral* in form although they were derived from an embryological columnar type. The cells of the gland ducts retain the original form, being cubical or columnar in type, or the larger ducts may possess a few layers of epithelial cells.

5. *Neuro-epithelium.* The rods and cones of the retina are sensory cells derived from embryonic ectoderm and are modified columnar cells. In the epithelium of the mucous membrane of the nose are found modified columnar epithelial cells which are the sensory cells of smell. Somewhat similar shaped cells occur in *taste buds*, the sensory end-organs of taste, located in the epithelium of the tongue. The sensory cells described are connected with the peripheral ends of afferent (sensory) nerve cells.

6. *Germinal.* The surface of the ovary is covered with a layer of cubical-shaped cells. From this layer, the ova are derived. The testis consists of tubules which contain cells from which, by a complicated process of spermatogenesis, the spermatozoa are produced.

7. *Stratified Squamous.* Not all epithelium consists of but one layer of cells, as indicated in the above types. The *epidermis* of the skin and the lining of the mouth, covering of the tongue, lining of the oesophagus and of the anus possess a many-layered epithelium, called *stratified squamous.* The deepest layer consists of

living cells somewhat columnar in shape. These cells possess the power of division. At each division, one of the daughter cells remains in the basal layer and grows to adult size and will later divide again. The other cell is pushed out of the basal layer into the next outer layer. Continued division, growth and migration of basal cells results in cells being constantly pushed out further and further from the basal layer, so forming the *strata* which vary in number in different localities. The outer and older cells gradually lose their vitality and become horny and mere scales (squamous) at the surface, where contact with external objects frees them. Callous skin formed on the hands as a result of physical labor is a number of layers of dead outer epidermal cells which protect the softer tissues within. Stratified squamous epithelium is always forming and always being worn away. It is one of the most important protective tissues of the body. With intact epidermis we can walk or can lift objects without pain. The accidental removal of a portion of epidermis reveals the degree with which healthful epidermis serves its purpose. It keeps out pathogenic Bacteria with which the surface of the body, and especially the hands, is constantly coming in contact. It prevents the rapid loss of water from the connective tissues beneath it. It contains no blood vessels although these are present in the connective tissue on which it rests.

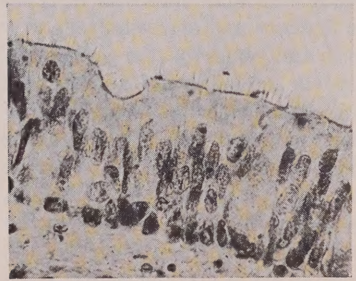

FIG. 313 *B*.—Pseudo-stratified epithelium. Photomicrograph by Cooper.

8. *Pseudo-stratified.* The superficial cells of this epithelium are columnar in type. The free surfaces are usually ciliated. The inner ends taper to a narrow process which extends to the basement membrane. Between the narrow basal ends of these long cells are smaller tapering cells of varying length, but *their* inner ends also extend below to the basement membrane. This type of epithelium has a stratified appearance but differs from stratified squamous in that *all* cells extend to the basement membrane. Ciliated pseudo-stratified epithelium forms the lining membrane of the trachea and its larger branches (Fig. 313 *B*).

Attention has already been called to the importance of an intact epithelium. Accidental destruction of a small area of stratified-squamous epithelium is usually easily repaired, due to formation of new cells from the basal layer — a process which goes on at all times. But when the simple columnar epithelium of the intestine or the squamous epithelium of the air sacs of the lung is injured to any extent, its repair takes place slowly and with difficulty because replacement is dependent upon division of cells on the borders of the lesion, and cell division in this type of epithelium is normally not so active as in the first case mentioned.

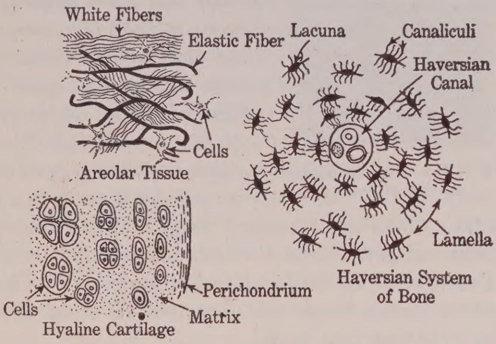

Fig. 314. — Connective tissues.

B. Connective Tissue (Fig. 314). Such a variety of tissues is found in this group that only a brief characterization is possible. Epithelium consists chiefly of cells, but in connective tissues the cells are few and often widely separated, and produce a great amount of intercellular substance which is the predominant part of connective tissue, and the connective or sustentative function of this type is served by the intercellular material. These tissues develop from mesoderm.

1. *Loose Fibro-elastic* or *Areolar Connective* tissue is one of the most common types. It consists of four structures. (*a*) *White fibers* are fine tissue threads arranged side by side in *bundles* which present a wavy appearance. The bundles branch, thus forming a network. They consist of an albuminous-like compound which when boiled yields *gelatin.* They are easily digested and are soluble in weak acids and alkalis. They are non-elastic. (*b*) *Elastic fibers* are fine, isolated branching tissue threads. They appear to be always somewhat stretched because on breaking the ends curl up and the pieces recoil. They are not readily digested by gastric juice and are not soluble in dilute acids or alkalis nor do they yield gelatin on boiling. They confer elasticity to areolar

tissue while the white fibers contribute strength to it. (*c*) In between the meshes of areolar fibers is *tissue juice.* This is a watery, colorless fluid or lymph. It consists of material derived from capillaries and from the cells of neighboring tissues. (*d*) *Connective tissue cells.* There are several varieties of these. Blood leucocytes are also present. (See Lymph, p. 371.) Areolar tissue connects the skin to the structures beneath it; it forms the supporting framework of the muscles, digestive tract, blood vessels, glands and other organs. If all the other tissues of the body were dissolved, leaving only the areolar tissue framework, there would still be left quite a complete model of the body and all its organs.

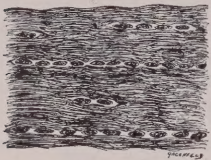

FIG. 315. — Longitudinal section of tendon.

2. *Dense Fibrous Tissue* (Fig. 315). A tendon is a strong cord of connective tissue connecting a muscle to a bone. Bundles of white fibers are arranged longitudinally and packed *closely together* with flat cells between the parallel bundles. A tendon is almost entirely dense white fibrous tissue. Thin *sheaths* of dense white fibrous tissue also form the covering of such organs as the liver, kidney and testis.

3. *Dense Elastic Tissue.* The principal unit of this tissue is the elastic fiber noted above. These form long, parallel, compact bundles separated from each other by thin investments of white fibrous tissue. They form a strong elastic cord such as the *ligamentum nuchae,* which is an important structure of support for the heavy head of a quadruped.

4. *Adipose Tissue* (Fig. 316). This is popularly known as 'fat.' The word 'fat' should be used to designate the principal chemical compound of adipose tissue. Adipose tissue consists of groups of fat cells which are held together by fibrous tissue. Fat droplets appear in connective tissue cells. The droplets increase in number, fuse and form a large globule of fat, which distends the cytoplasm so that it is but a mere film with the nucleus at some point in it. Adipose tissue commonly accompanies areolar tissue and is noted in the subcutaneous tissue, and around the mesentery, kidneys, adrenals and heart. When fat is used up in

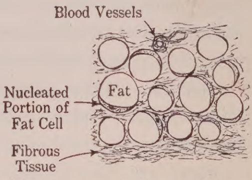

FIG. 316. — Adipose tissue.

the metabolism of starvation, the cells resume an appearance much like that of the original connective tissue cell from which they originated. Osmic acid stains fat black.

5. *Cartilage* (Fig. 314) is a firm, supporting, connective tissue. It has a solid ground substance called the matrix in which the cells are distributed. Cartilage has no blood vessels or nerves. There are three varieties: (*a*) Hyaline cartilage is found in the trachea and larger bronchial tubes, and at the ends of long bones. It forms the cartilaginous part of the nose and larynx and connects the ribs to the breastbone. The matrix is a clear, translucent, intercellular ground substance. The cells occur in little spaces called lacunae. A single cell in a lacuna may divide, forming two daughter cells in the same lacuna. Each daughter cell may then form matrix so that the two gradually grow apart. Sections of hyaline cartilage show single separate cells and cells in groups of two to eight. Cartilage is surrounded by a special dense-fibrous membrane called *perichondrium.* The side of the perichondrium next the cartilage plate has many small cells from which new superficial matrix is developed. (*b*) Elastic cartilage. This is hyaline cartilage in which the matrix is further specialized by the inclusion in it of elastic fibers, although the superficial layer is purely hyaline in character. Around it is a fibrous perichondrium. It forms the skeleton of the external ear. (*c*) Fibrocartilage. This type is a combination of hyaline cartilage and dense white-fibrous tissue. It has no perichondrium. It forms buffer-like pads between the vertebrae of the backbone and is found elsewhere.

Perichondrium connects cartilages to the surrounding connective tissues. It contains blood vessels, lymphatics and nerves. The nourishment of cartilage is derived from the blood vessels of the perichondrium.

The skeleton of Elasmobranchs is entirely of cartilage. Many of the bones of the higher Vertebrates are preformed in cartilage, which is replaced by bone during development.

6. *Bone* (Fig. 314). This is a more rigid connective or supporting tissue than cartilage, which is not firm enough to be the skeletal framework of animals moving about on the land. However, transition from water to terrestrial life did not cause the change from cartilage to bone since the latter forms the skeleton of teleost fishes.

Flat bones, such as those of the face and top of the skull, are formed from embryonic membranes and hence are called *membrane bones*. The bones of the limbs, on the other hand, and many other bones of the skeleton are preformed in cartilage and hence are known as *cartilage bones*.

Flat bones present an outer and inner superficial layer of compact bone. The narrow region between is occupied by spongy bone, the spaces of which are occupied by marrow. The *long bones* possess a cylindrical shaft of compact bone surrounding a marrow cavity. At either end of such a long bone are the *epiphyses* or ends, each of which has a superficial thin layer of compact bone and an internal portion composed of spongy bone, the spaces of which are filled with red marrow. The epiphyses of long bones are capped with hyaline cartilage forming the *articular cartilages*.

The shaft of a long bone consists of a series of *lamellae* or bony layers. Four types of these are present. (*a*) The greater part of the substance of the shaft consists of several *Haversian systems* running lengthwise of the shaft. Each Haversian system consists of several concentric *lamellae*. In the center of each system is an Haversian canal about 0.07 mm. in diameter. In life it is occupied by blood vessels, nerves, lymphatics, marrow cells and connective tissue. Surrounding the central canal are concentric Haversian lamellae. Within and between each lamella are many small spaces called *lacunae*. From each lacuna, microscopic canals called *canaliculi* radiate out in all directions and communicate with canaliculi of lacunae of adjacent lamellae. In life each lacuna is occupied by a bone cell which has fine processes, each of which projects into a canaliculus. The Haversian canals extend parallel with each other lengthwise of the shaft, but also branch to connect with neighboring Haversian canals. Branches extend to the outer surface of the shaft and also to the marrow cavity so as to permit the entrance of blood vessels and nerves, which extend throughout the entire system of Haversian canals. (*b*) The spaces between adjacent Haversian systems are occupied by *interstitial lamellae*, which are incomplete Haversian lamellae but similar in structure. (*c*) Adjacent to the marrow cavity are *internal circumferential lamellae*. (*d*) Externally just within the outer surface are a few *external circumferential lamellae* which are also similar in structure to the Haversian lamellae.

The surfaces of bones, with the exception of the epiphyses which are capped with articular cartilages, are covered with a close-fitting, dense, fibrous sheath called the *periosteum*. It supports blood vessels and nerves. In young and growing bones, in the inner portion of the periosteum are many small bone-forming cells called osteoblasts. In older bone this inner portion contains less of these cells. However, if a portion of bone is destroyed, sufficient bone-forming cells are present in the periosteum to repair the loss. Lining the marrow cavity is a delicate fibrous layer similar to the periosteum.

Bone marrow consists of a very fine fibrous connective tissue containing fat cells, blood vessels, bone-forming cells and special marrow cells. There are two varieties of marrow, *yellow* and *red*. The yellow marrow is largely fat tissue. The red marrow contains a small amount of fat but more blood vessels, blood cells and marrow cells. In older bones, the shaft is occupied by yellow marrow but the red or embryonic type of marrow persists in the epiphysial portions and possesses the cells from which the blood cells are formed in adult life.

C. Muscle Tissue. This is the special contractile tissue of animals. It is derived from mesoderm. The following types of muscle tissues are distinguished.

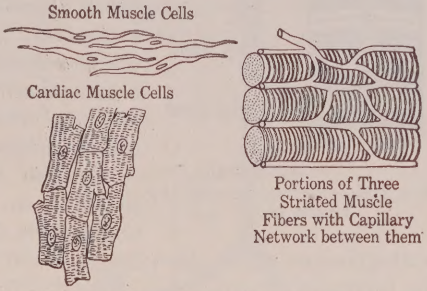
Smooth Muscle Cells
Cardiac Muscle Cells
Portions of Three Striated Muscle Fibers with Capillary Network between them

FIG. 317. — Types of muscle tissue.

(1) *Smooth* or *Plain Muscle* (Fig. 317). It is composed of long, tapering cells each possessing an elongated nucleus in the middle and thicker portion of the cell. These cells are arranged alongside one another. In vertebrates the cells are closely connected with one another and masses of them are held together by a delicate fibrous connective tissue. The cells are from 50 μ to 500 μ in length. When contracted, they are shorter and thicker. In the vertebrate they are involuntary. In the vertebrate intestine there is a cylindrical layer of smooth muscle cells arranged lengthwise of the tube. Toward the lumen is a second cylindrical layer whose cells are arranged at right angles to the length of the tube. Contraction of the first or outer layer causes a shortening of the intestine

at the point of contraction. Contraction of the inner muscle layer causes a decrease in the size of the lumen of the intestine at that point. But both layers contract in concert, and moreover, contraction at any point initiates a contraction in the region just beyond. The result is a contraction wave preceded by and followed by a local relaxation. Wave after wave succeed each other, constituting what is known as *peristaltic contraction.* In the intestine, this movement mixes food and enzymes, aids chemical action in digestion, aids absorption and keeps the contents of the intestine moving. The walls of arteries and veins, vas deferens, oviducts, ureters and bladder all possess layers of smooth muscle compounded with connective tissue.

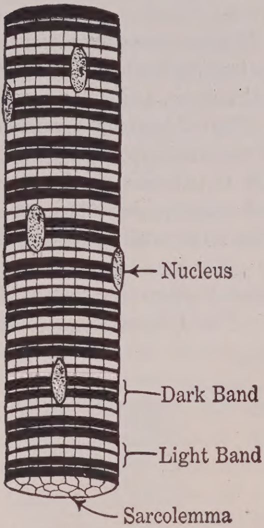

FIG. 318. — Portion of a striated muscle fiber.

(2) *Striated* or *Voluntary Muscle.* This forms the greater part of skeletal muscles which, with the skeleton, forms a great part of the locomotor mechanism. The histological unit of striated muscle is not a single cell, but a syncytium of cells forming a long, slender, microscopical rod-like unit called a muscle fiber. It is from 50 mm. to 130 mm. in length and from 10 μ to 100 μ in diameter. The striated muscle fiber (Figs. 317 and 318) is so-called because of the *alternating light* and *dark* transverse bands to be observed even in living muscle. There is an outer delicate sheath called the sarcolemma, the representative of the original cell membrane of the myoblast or embryonic cell from which the fiber developed. Within the fiber are long thread-like elements called *sarcofibrils,* imbedded in a more fluid *sarcoplasm.* Many nuclei occur along the fiber toward the surface. Capillaries occur between adjacent fibers, these being connected by branches to form a network. Finger-like peripheral ends of motor nerves terminate among striated muscle fibers, forming *motor end plates.* The peripheral ends of sensory (afferent) nerve also end around smaller, modified muscle fibers constituting sensory end organs of the

muscle sense. When a muscle fiber contracts, it becomes shorter and thicker and the differences in length of all the fibers are evident in the contraction of the muscle as a whole.

(3) *Cardiac Muscle* (Fig. 317). This type of muscle tissue is restricted to the heart. The vertebrate heart is composed of oblong-shaped cells whose ends branch, and these connect with other cells forming a network of interconnected parallel fibers, contain long fibrils and are also cross striated. The cell membranes are not present, so that cardiac muscle is a *syncytium.* A nucleus is in the center of each cytoplasmic cell mass. By the contraction of cardiac muscle the chambers of the heart are decreased in size and due to the presence of valves, blood is effectively *pumped* from auricles to ventricles and from the latter to the great aorta and pulmonary artery. The action of cardiac muscle is rhythmical, vigorous, powerful, up to the mark and unceasingly at work as long as life lasts. Its intrinsic action does not appear to be dependent upon motor nerve impulses, which is true of voluntary muscle.

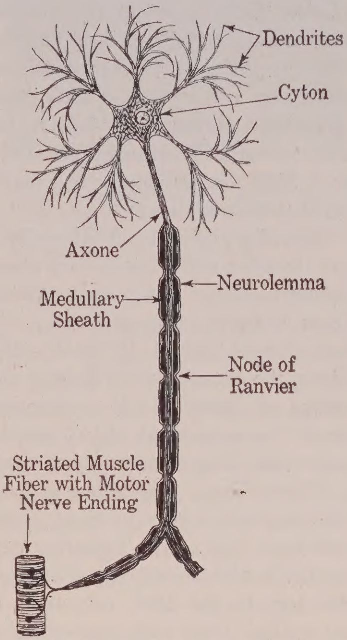

FIG. 319 *A.* — Diagram of a neuron.

D. Nerve Tissue. The general function of nerve tissue is to conduct impulses from sense organs to muscles or glands and its importance as an agent of adjustment has been emphasized. Nerves, spinal cord and brain are derived from ectoderm.

The Neuron. The histological unit of nerve tissue is called a neuron (Fig. 319 *A*). It is a highly specialized cell of which there are many varieties. A typical nerve cell or neuron possesses (*a*) a cell body containing a nucleus surrounded by cytoplasm. This portion of the neuron is called the *cyton.* (*b*) Extending from it are short, thick, irregular and branching processes called *dendrites* and (*c*) a long, single, thread-like process or *axone*. In general, the function of the dendrites is to pick up nerve impulses from the terminals of another neuron. The cell body is the center of metabolic activities of the entire neuron and probably amplifies impulses aroused in it by impulses from a connecting cell. The axone conducts these impulses to another neuron or possibly to a motor end plate in a muscle. The cytoplasm of the cell body contains a network of fine fibers imbedded in a more fluid neuroplasm. Mitochondria are present in it also. In addition, other bodies called Nissl granules are present. They exhibit modifications in different physiological and pathological conditions more than any other neuron structures. The dendrites resemble the cytoplasm of the cyton in structure. The axone consists of long fine neurofibrils arranged parallel with one another and imbedded in a fluid neuroplasm. The neurofibrils are continuations of the fibril system of the cyton.

Medullary Sheath. Within the brain and spinal cord, the axones are invested with a *medullary sheath* composed of a fatty substance called *myelin*. If the axones pass out from the central system to form a nerve, they possess a thin nucleated sheath called the *neurolemma*, which is outside the myelin. At regular intervals along the axone, the medullary sheath is constricted, forming the nodes of Ranvier. It is suggested that the axone is nourished from the outside at these points, some of which are at a comparatively long distance from the cyton.

Nerve Fiber. The axone and its covering is called a nerve fiber. Medullated axones vary in diameter from 2 μ to 20 μ. Some are very long. For example, cytons located in the spinal cord in the lumbo-sacral region have axones extending in nerves down the legs to the toes, *i.e.*, over 1,000,000 μ long. It is difficult to realize that such exceedingly fine thread-like processes are parts of a single cell, the nucleus of which is *far away* from the end portions of the axone. The proof of this required long, patient research, of which two contributions will be noted.

Golgi devised a method of technic in which silver chromate or some other silver salt forms a precipitate in the nerve cell, coloring all parts of the neurons black but not staining other substance. When rather thick sections are thus prepared, nerve cells or portions of them are clearly and definitely visible (Fig. 319 *B*). The study of successive sections indicates the connection between cyton and axone.

More recent than the work of Golgi is that of Harrison, who demonstrated that axones and dendrites *grow out* of the nucleated portion of an embryonic nerve cell. Near the peripheral end, the axone branches, and thus forms its terminal arborization. If this is within the brain or spinal cord, it is in contact with the dendrites of another neuron into which it conveys its impulse. The connection between the two cells is one of *contact* and is called a *synapse*. Impulses pass over neurons in one direction, *i.e.*, dendrites to cyton and from cyton to axone. The nervous system is an orderly but exceedingly complex organization of connecting neurons.

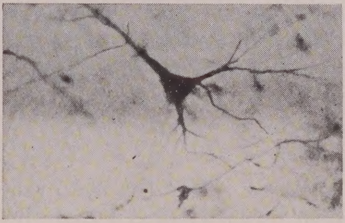

FIG. 319 *B*. — Photomicrograph of a pyramidal (motor) cell in cerebral cortex—Golgi technic. The triangular body is the cyton, branches are dendrites, — axone not shown. Photo by Cooper.

Divisions of Nervous System. The nervous system is divided into (*a*) the central system, composed of the brain and spinal cord; (*b*) the peripheral system, composed of the cranial and spinal nerves; and (*c*) the sympathetic system. Peripheral nerves are white cords containing nerve fibers (*i.e.*, axones with their sheaths) and bound together and covered with connective tissue. Their cytons are for the most part within the brain and spinal cord. The sympathetic system consists of a set of fine nerves supplying especially the organs of the abdominal and thoracic cavities. Associated with these nerves are ganglia. These are small enlargements containing cytons and so are locations where synapses of neurons occur outside the central system. The brain and spinal cord are composed of gray and white matter. The gray matter contains cytons, dendrites and portions of axones originating in the cytons present in it. White matter consists of masses of medullated axones. The gray matter of the cerebellum and cerebrum forms a thin external layer or cortex, while most of the body of these two parts of the brain consists of white matter. The cortex is about 2.5 mm. thick and that of the cerebrum contains several zones of cytons distributed at different levels throughout its thickness. Strong says that there are probably ten billion cytons in the cortex of the cerebrum alone. The cortex of the human brain has an area of over 200,000 sq. mm. Such a great expanse can be accommodated within the confines of the skull, because the cortex is arranged in a series of foldings or convolutions. The indicated connections between neurons is more marvelous than their numbers.

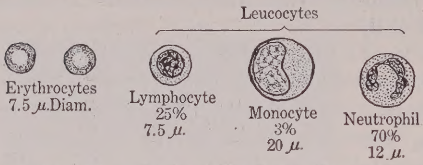

FIG. 320. — Types of blood cells (human).

E. Blood (Fig. 320) has often been called a tissue. It originates from embryonic mesoderm and consists of plasma and cells.

Plasma. This is a fluid, which is studied by chemical rather than by histological technic because it consists of water, salts, respiratory gases, sugars, fats, proteins, enzymes, hormones, vitamins as well as urea and other wastes of metabolism.

Cells. Blood transports special and unique cells. There are two kinds.

(*a*) *Erythrocytes, or Red Blood Cells.* The red blood cells of Vertebrates, except Mammals, are flat, oval-shaped and nucleated discs. The blood cells of Mammals are not nucleated although they arise from cells that are nucleated. Human red blood cells are thin biconcave discs about 7.5 µ in diameter. Each cubic centimeter of male human blood contains in health about 5,000,000 erythrocytes per cu. mm. and female human blood contains about 4,500,000 per cu. mm. In the adult, erythrocytes are formed by a series of mitoses from cells in the red marrow of flat bones and at the ends of long bones. Each red blood cell has a somewhat greasy external membrane inclosing the substance of the corpuscle. One of the important compounds of this is hemoglobin, a protein-iron compound having a chemical affinity for oxygen. The function of red blood cells is to carry oxygen from the lungs to the tissues. They also probably carry a certain amount of carbon dioxide back to the lung membranes. Normal plasma has a concentration equivalent to a 0.9% solution of sodium chloride and is *isotonic* with the saline concentration of the corpuscle. Ashby states that red blood cells have an average life of about thirty days. After they are produced in the red marrow, erythrocytes enter the blood stream, where they remain until functionless. It is thought that one function of the spleen is to remove these worn-out red cells from circulation and to destroy them. It is also believed that their iron is conserved.

(*b*) *Leucocytes, or White Blood Cells.* They are fewer than erythrocytes, averaging about 8,000 per cu. mm. of blood. There are several varieties of these cells. (1) Lymphocytes. These are round cells about the size of an erythrocyte or a little larger. They have a very large nucleus with a small outer ' rind ' of cytoplasm. They form about 20% of the leucocytes, are amoeboid but are not phagocytic. They are formed in lymph glands, spleen and red bone marrow. (2) Monocytes. These are large cells about 18 μ in diameter, have a large kidney or horseshoe-shaped nucleus, are remarkably phagocytic and constitute about 5% of the leucocytes. (3) Neutrophils. They are about 10 μ in diameter. The finely granular cytoplasm stains lilac color with a combination of eosin and methylene blue dyes. They are amoeboid and actively phagocytic. They make powerful proteolytic enzymes which act inside or outside them. They are chemotactically attracted to injured or infected tissues and are found in pus. The nucleus occurs in sausage-like links. They are the most numerous of the leucocytes, constituting between 60% and 70% of these cells. (4) Eosinophils form about 3% of the leucocytes and are about 12 μ in diameter. They are amoeboid but not phagocytic. The coarse granules have an affinity for eosin (acid dye). (5) Basophils are about 10 μ in diameter and are very few in number (0.5%). The nucleus has a variety of shapes. The coarse granules stain with basic (methylene blue) dyes. (6) Platelets. These are very small bodies about 3 μ in diameter. The presence of a nucleus is problematical as is also the question of their origin. It is thought that in cases of bleeding they liberate *thrombin,* the enzyme so essential to the clotting of blood. (7) Megakaryocytes. Although not found in circulating blood, they should be considered in the study of blood. They are giant cells, being from 30 μ to 100 μ in diameter. They are not found, therefore, in circulation, but are found in the blood of red bone marrow. They are regarded as large lymphocytes but non-phagocytic. They may have a very large nucleus, having sausage-like pieces, or these may occur separately. Some of the cells have pseudopodia-like processes.

Lymph. This is a colorless fluid present in tissues. Physiologically it is the middleman between blood vessels and tissue cells.

Water, salts, foods, etc., pass out from blood vessels into it and cells absorb these as needed from it. Cells discharge their wastes of metabolism into it. It is chiefly returned to the large veins in the neck by a special system of lymphatic vessels. From the veins, it again enters the general circulation. The chemical nature of lymph will not be considered here. A histological study of lymph involves a study of its special cells. These are lymph corpuscles and are recognized as blood leucocytes. Most of the cells are *lymphocytes* which are formed in the many lymph glands through which lymph flows in its circulation in the lymphatic vessels on its way to the heart. Lymph contains fat droplets and animal starch, glycogen. When an animal is fed on fat, the latter is absorbed from the intestine a few hours later. If the abdominal cavity is then opened, the lymph channels in the mesentery appear as milky cords because they contain so many droplets of fat. The circulation of lymph is in one direction, namely, *toward the heart.* In order to return from the tissue spaces, it enters the peripheral ends of small lymphatic vessels.

Tissue Construction of Organs

The various organs of the body are constructed of the different tissues just described. Some organs contain a predominance of some *one* of the five enumerated. In some organs all kinds of tissues are represented more or less equally. The following examples illustrate this organization.

(1) **Blood Vessels.** (*a*) Capillaries. These are minute tubes forming a network. The walls are composed of flat, squamous, epithelial cells. (*b*) Arteries vary in size but are larger than capillaries. They are lined with the same type of squamous epithelium that forms the entire capillary wall but have in addition outer layers of smooth muscle and fibro-elastic connective tissue. The walls of the larger branches have blood vessels of their own, and nerves. (*c*) Veins are similar in tissue composition to arteries, but the amount of smooth muscle and connective tissue is less. In veins and arteries, therefore, we find represented epithelium, connective tissue, muscle tissue, nerve tissue and blood.

(2) **Oesophagus** (Fig. 321). The histologic structure of the entire gastro-intestinal tract is similar in general but differs in details. The oesophagus, for example, is connected to the adjacent structures of the neck by fibrous connective tissue. Within this

is a zone of muscle. In the upper part of the oesophagus this is striated, while toward the stomach it is smooth muscle. Within the zone of muscle is a zone of fibro-elastic connective tissue forming the submucous coat, and within this is the mucous membrane. The mucous membrane consists first of an external thin coat of smooth muscle, then a *tunica propria* of fibro-elastic tissue, and on this is stratified squamous epithelium, forming the lining coat, *i.e.*, the internal wall of the lumen. Connective tissue and muscle are quite equally distributed in the oesophagus and the epithelium is prominent.

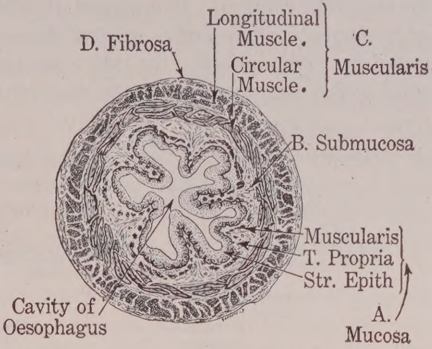

FIG. 321. — Cross-section, oesophagus of cat.

(3) Pancreas. The location of the pancreas has already been indicated. (*a*) The pancreas is a compound tubular-alveolar gland that secretes enzymes concerned in digestion of food in the digestive tract. All the cells concerned in producing and discharging the secretions are epithelial cells. The secretions formed pass through the duct system into the duodenum. (*b*) The pancreas also contains patches of modified epithelial cells forming the Islands of Langerhans. These are surrounded by capillaries. The Islet cells secrete a hormone into the blood. This hormone governs the metabolism of sugar elsewhere. Connective tissue sheaths support the lobes and lobules of the pancreas. The connective tissues support nerves, blood vessels and lymphatics. The pancreas is predominantly epithelial.

(4) The bony framework of the body is chiefly connective tissue, namely, bone. But many of the bones are covered with a fibrous periosteum and the ends of long bones are covered with hyaline cartilage. Moreover, bones are penetrated by blood vessels and nerves. So all types of tissues are present in bones.

(5) Skeletal muscles are anatomical organs. The chief tissue composing them is striated (voluntary) muscle fibers. But these are *harnessed* in sheaths of fibro-elastic connective tissue. There is first an external covering sheath of this called the epimysium.

Extensions of this pass within, forming bundles of fibers separated from each other by similar connective tissue sheaths called *perimysium.* Finer extensions of the *perimysial* tissue pass in between the individual fibers. The connective tissues support blood vessels and nerves.

(6) **Spinal Cord** (Fig. 322). It is located in the spinal canal of the vertebral column. It is *almost* divided into two lateral halves by a *dorsal septum* and a *ventral fissure.* The two halves are united by a commissure. In this commissure is located the spinal canal which communicates with the ventricles of the brain. A study of a typical cross-section of the cord shows the above features. In addition we can see the central or inner *gray matter* surrounded by *white matter.* The gray matter has the appearance of a broad letter " H " or " X." The two dorsal expansions of gray matter are the *dorsal horns* and the two ventral expansions are the *ventral horns.* Tissue from each horn extends beyond the cord at intervals to form the *dorsal* and *ventral roots* of the spinal nerves originating at that level. On the dorsal root is a *spinal ganglion.*

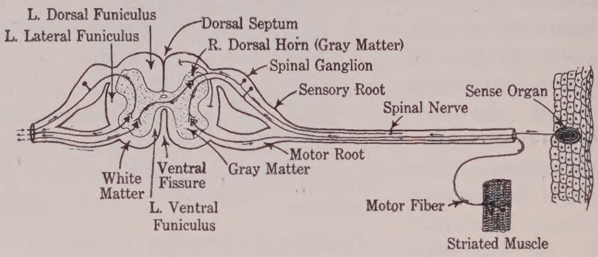
L. Dorsal Funiculus
L. Lateral Funiculus
Dorsal Septum
R. Dorsal Horn (Gray Matter)
Spinal Ganglion
Sensory Root
Sense Organ
Spinal Nerve
Motor Root
Gray Matter
White Matter
Ventral Fissure
L. Ventral Funiculus
Motor Fiber
Striated Muscle

FIG. 322. — Diagram showing structure of spinal cord and connection of a spinal nerve with it. Structures involved in a simple reflex also shown.

The white matter occurs in three masses or *funiculi* on either side. (1) The (two) *dorsal funiculi* are located on either side of the dorsal septum and medial to the dorsal horns. (2) There is a *ventral funiculus* on *either side* of the ventral fissure and medial to the ventral horns. (3) There is a *lateral funiculus* on either side of the cord between the dorsal and ventral horn of that side. The funiculi are composed of nerve fibers extending lengthwise of the cord. The fibers of the dorsal funiculi carry afferent impulses up the cord, while the ventral fibers carry efferent impulses down the cord. The lateral funiculi contain groups of afferent fibers and groups of efferent fibers. It has been ascertained that the fibers of the funiculi are arranged in well-defined fiber tracts, carrying certain groups of impulses from certain stations to certain other stations. The nerve fibers involved are chiefly the axones of neurons and are parts of pathways extending from peripheral sense organs to the cord and up this to the brain and from this back down the cord and out to muscles or glands.

The gray matter of the cord contains cytons, their dendrites and axones arising from cytons. Let us consider some of these. Cytons located in the ventral horns have axones which pass out via the ventral nerve roots into the spinal nerve. Other cytons in the gray matter have axones which turn out into the funiculi and extend up or down the cord. Axones extend from one horn across the commissure to the horn on the other side. Some neurons are confined entirely to the gray matter. Axones from the dorsal roots extend into the dorsal horns.

(7) Spinal Nerve. Let us now study the histology of a spinal nerve. The dorsal and ventral roots meet just outside the cord (Fig. 322). The ventral root contains only motor fibers. The dorsal root contains sensory or afferent fibers. But there is an enlargement on the dorsal root called a *spinal ganglion*. This is chiefly an assemblage of somewhat pear-shaped cytons from which one process arises. But this process almost immediately divides into two. One of these, the *peripheral* process, extends out into the spinal nerve, while the other *central* process extends into the dorsal horn. (*a*) The central process within the dorsal horn has a branch which continues in the gray matter and forms a synapse with a motor cell in the ventral horn. Another branch may connect with a cyton whose axone extends across the commissure and out into the lateral funiculus of the cord and up in this to higher neurons. Another branch may enter the dorsal funiculus. (*b*) The peripheral branch of the ganglion cell extends out in the spinal nerve and ends, for

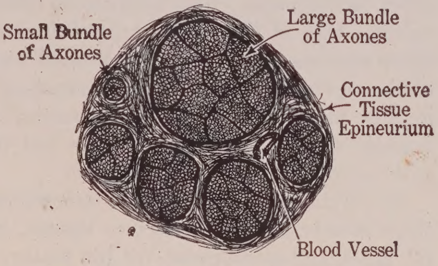

FIG. 323. — Cross-section of a small nerve.

example, in a peripheral sense organ of touch. The roots form the nerve.

The spinal nerve (Fig. 323) is a cable whose component elements are afferent *and* efferent nerve fibers. The entire nerve, its roots and the spinal ganglion are invested with a fibrous connective tissue sheath called the *epineurium*. From this extensions pass into the nerve, forming bundles of nerve fibers separated from each other by connective tissue sheaths (*perineurium*). The connective tissue extends also in between the individual fibers. The supporting connective tissue contains blood vessels and even nerves.

(8) **Brain.** We shall discuss this in general terms only. From a histological point of view it contains internal nerve centers which resemble ganglia in being assemblages of cytons and their processes, where connections are made with neurons carrying impulses from above or from below. The greater mass of the brain is composed of *white matter* or, in other words, conducting fibers. In the cerebrum and cerebellum, the *gray matter* forms an external rind or *cortex,* which has already been explained. The entire nervous system is a very complicated system of pathways, forming many simple reflex mechanisms, many complex reflex mechanisms and many more so complicated or involved that they can hardly be called reflex mechanisms. The number of neurons involved in a reflex varies. One of the simplest involving the cerebrum, consists of three neurons between the peripheral sense organ and the cortex of the cerebrum, one or more association neurons conducting the impulse to a motor neuron in the cortex; and this cell carries the impulse down the cord, where its end branches form a synapse with a motor cell of a spinal nerve.

The brain and spinal cord are inclosed in the *meninges,* which are three membranes of connective tissues, namely (*a*) dura mater; (*b*) arachnoid membrane; (*c*) pia mater.

(*a*) The *dura mater* is the outermost of these coats. Its outer face is in close contact with the inner face of the bony cavities in which the brain and cord are located. The outer part of the dura is similar to periosteum. The dura is composed of fibrous connective tissue and is richly supplied with lymphatic vessels but not many blood vessels.

(*b*) The *arachnoid* is a thin membrane between the dura and pia. It is delicate areolar tissue. Between the arachnoid and the pia is the subarachnoid space filled with lymph-like cerebro-spinal fluid.

(*c*) The *pia mater* closely invests the cord and brain, entering all the fissures, and extends even into the substance of these organs, carrying blood vessels with which it is well supplied.

It is evident therefore that although the nervous system is composed chiefly of nerve tissue, nevertheless the other types of tissue are present.

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CHAPTER XXI

COMPARATIVE ANATOMY

Introduction. In the three preceding chapters we have studied (*a*) the cell; (*b*) we reviewed briefly the development of the animal from the fertilized egg-cell stage, and (*c*) we distinguished the principal tissues of which the organs are composed.

We have learned that there are three great groups of physiological processes: (1) those more intimately associated with metabolism; (2) those of adjustment and (3) reproduction. All these functions are performed by the simple one-celled Protozoa as well as by the highly specialized Mammal. In our studies of animals, we found as we proceeded that special organs were found in the higher forms for the carrying on of particular functions. With the increase in number of cells, elaborate specialization of organs is necessary to enable every cell to function properly, and proper functioning of every cell involves basic and functional metabolism. Great elaboration of organs of adjustment makes possible a greater feeding range; greater protection against enemies; greater freedom from the restrictive effects of changing environmental conditions — in short, greater control of nature.

A single-celled animal, such as the Amoeba, needs food. It seeks its food, devours it, and within the province of its single-celled body occur not only the processes of metabolism but also those of adjustment and reproduction. In the case of the dog, however, an elaborate set of organs must function before each and every cell in its body can even receive food for basal and functional metabolism.

We shall now study the comparative anatomy of animals in order to gain a broader conception of morphology. Because of limited space, we shall confine this study chiefly to a study of the comparative anatomy of Vertebrates although references will be made to lower forms. Furthermore, the organs involved in the function of reproduction will be omitted, since a special chapter on this subject will include a general review of the *organs* and *methods* of reproduction in *all* animals together with a few considerations that are not limited to the field of comparative anatomy.

It will be found that the generalizations now presented constitute an important body of evidence in support of the theory of organic evolution.

As stated above, in this chapter we shall consider the comparative anatomy of the organs of metabolism and adjustment. Properly speaking, metabolism is a name applied to those chemical processes taking place *within the cell* whereby it performs its special work and also maintains life activity, *i.e.*, functional and basic metabolism. But the organs of digestion, respiration, circulation and excretion, for example, are closely associated with making cellular metabolism possible. On this account we have taken the liberty of calling such structures *organs* of metabolism. Moreover, the organs of adjustment are also concerned, though more remotely, with making possible the basic and functional metabolism of cells. It should also be remembered that both are concerned primarily with the life of the individual that possesses them, and basic to its reproductive functions.

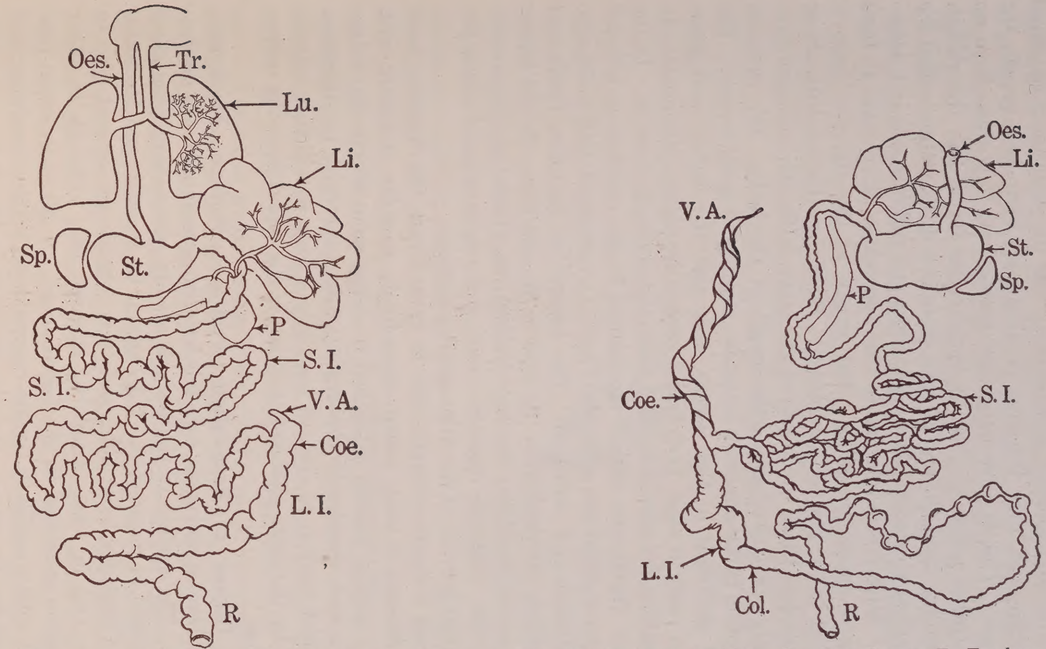
I. Comparative Anatomy of Organs Primarily Related to Metabolism

A. Organs of Digestion. (*a*) *Lower Animals.* Neither Protozoa nor Sponges have definite organs of digestion. In Coelenterates there is a blind sac with one opening serving as a mouth and anus. In Hydra this sac is somewhat tubular in form and is composed of endoderm cells. Endoderm appears early in the development of higher animals and forms the lining of the digestive tract in all of them. It also forms glands whose secretions are concerned in digestion. In the Flatworms the digestive tract is still a blind sac of endoderm, but the sac is not a simple tube. It has many diverticula and extends to all parts of the body. In the Roundworms there is a straight intestinal tract with mouth and anus. In Annelids the digestive tract shows indications of specialization. The Earthworm has a pharynx, oesophagus, crop, gizzard, and intestine ending in an anus. The crop and gizzard may be considered a sort of stomach. In Arthropods the arrangement is somewhat similar, that is, mouth, oesophagus, stomach, and intestine, though the tube shows various special structures in different groups of this phylum. Studied from the viewpoint of the kind of food eaten, these special structures are seen to be adaptively modified.

(*b*) *Vertebrates.* A striking similarity of plan is seen in the digestive tract of Vertebrata although the general plan shows ample adaptive modifications (Fig. 324). Associated with the mouth are (*a*) teeth, and (*b*) from Amphibians upward, also *salivary glands* and (*c*) the *tongue*, which is *glandular* and *sensory.* In *Dipnoi* and forms above, the nasal sacs open into the mouth.

Behind the mouth is the *pharynx.* On the side walls of this in fishes are *gill clefts.* The *Eustachian tubes* of higher Vertebrates are the modified *spiracular clefts* of Elasmobranchs. The gill clefts functional in Fishes and Amphibians are present only in the embryos of Reptiles, Birds and Mammals for a short time. The skeletal supports of the gills of Fishes and Amphibia are modified for different uses in higher forms. The *thyroid* and *thymus glands* are associated with the pharynx, arising from it in the embryo but later losing their original connection. Associated with the pharynx is the *swim bladder* of fishes, which usually originates dorsally; and in land Vertebrates, the *lungs,* which originate ventrally. These outgrowths of the digestive tracts are not concerned with digestion. The pharynx leads into the *oesophagus.* This simply carries the food down to the *stomach.* The stomach is an enlargement of the digestive tube where food compounds undergo a partial simplification or digestion. On the whole it is saccular in form. Two portions are recognized — the *cardiac* or oesophageal end, and the *pyloric* or intestinal end.

Different types of glands are present in great numbers in the wall of the stomach. The special modifications of the stomach in birds and ruminant mammals are recalled here. Animals could do without a stomach if they were given the form of food the stomach prepares. Close behind the stomach of most Vertebrates are found two glands connected with the first part of the intestine next to the stomach. These are the *liver* and the *pancreas.* They have to do with the digestion of food within the intestinal tract or chemical changes elsewhere. The intestine is divided into two portions: a longer *small intestine* of small diameter and a shorter *large intestine* of large diameter. Most digestion occurs in the *small intestine.* Its internal surface is increased by various folds or outgrowths and its wall contains multitudes of glands concerned


Oes.
Tr.
Lu.
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S. I.
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R
V. A.
Oes.
Li.
St.
Sp.
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S. I.
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L. I.
Col.
R

FIG. 324. — At left, diagram of digestive tract of dog; at right, digestive tract of rabbit. Oes. Oesophagus; Tr. Trachea; Lu. Lung; Li. Liver; Sp. Spleen; St. Stomach; P. Pancreas; S. I. Small intestine; V. A. Vermiform appendix; L. I. Large intestine; Col. Colon; Coe. Coecum; R. Rectum.

with digestion. In the *large intestine* the unabsorbed material is prepared for expulsion or defecation. At the junction of the small intestine and large intestine of Mammals there is a pouch, the *coecum*. This is very long and tubular and important from an absorptive point of view in herbivorous forms like the rabbit. Extending from the end of this, there is a diverticulum called the *vermiform appendix*. It is very short and rudimentary in Carnivora. Infection developing in this appendage often leads to fatal cases of blood poisoning. The length of the digestive tract is related to the kind of food eaten. Herbivores have a tube about twenty-five times the length of the body, while that of Carnivores is only about five times the length of the body. However, an exception is the sea-lion's intestine, which is of great length. The hind gut ends in the *cloaca*. Into this the ureters and gonaducts open in most Vertebrates except the higher Mammals. In Amphibia, the *cloacal bladder* grows out ventrally from it. In the higher Vertebrates this is represented in the embryo by a foetal structure called the *allantois* (Fig. 311), concerned with embryonic respiration and nutrition. The *bladder* of Reptiles, Birds and Mammals develops from the base of the allantois. In the higher Mammals, the cloaca becomes divided into a faecal portion, associated only with the digestive tract, and a urino-genital sinus, the terminal portion of the urino-genital systems.

From a simple straight tube in lower forms, the digestive tract has become a long, coiled, exceedingly complex structure with many special regions concerned in doing more effectively, extensively and completely the various jobs concerned in digestion. Its chief work is to convert food into a form in which it may be used by the body cells and to separate the useful from the useless portion.

B. Organs of Respiration. Protozoa, Porifera, Flatworms, Roundworms and some Annelids have no special organs of respiration. The surface of the body is readily permeable to the gases concerned in respiration. *Gills* appear in Annelids and Mollusks. The Crustacea have gills, and these organs are present also in fishes and in some Amphibia through life, although in other Amphibia restricted to the larval stage. A gill is an organ provided with a capillary system covered with a thin membrane and surrounded by water. Oxygen dissolved in the water can easily permeate the membrane of the gill and enter the blood of the capillary, and similarly CO_2 can easily pass from the blood through the wall of the capillary and gill membrane into the water. Gills may be leaf-like or like a tuft of hairs or slender processes. In the aquatic dragon-fly nymph, the hind gut is filled with plate-like gills. In certain Fish, Insects and Worms, the hind gut may be filled with fresh water from time to time and so serve as a respiratory organ. The cloacal bladder of the frog is thought to serve in this way at times.

Outside air is delivered directly to the various tissue cells through a complicated system of tubes called *tracheae* in the case of insects.

In Reptiles, Birds and Mammals, gill clefts are formed in the embryo, and paired lungs are later formed from the ventral side of the embryonic gut. In Dipnoi, the dorsal air sac is supplied with pulmonary blood vessels and serves as a sort of lung. Developing as sacs associated with the digestive tract (*pharynx*) and inside the body cavity, the lungs are protected. The respiratory surfaces continue to be moist in all forms. Lungs are relatively simple sacs in Amphibia (Fig. 325). The inside walls are honey-combed with little chambers or *alveoli*, whereby the total respiratory surface is somewhat greater than the total external surface of the lung. In the Reptile the lung is relatively larger and more complex. There is a great increase in the number of air sacs or alveoli, and in the interior of the lung of the turtle there is an open passageway. In the Bird and Mammal the lungs consist chiefly of branching bronchial tubes terminating in multitudes of microscopic air sacs, whose membranous walls contain pulmonary capillaries. Thus a much greater extension of respiratory surface is packed into a small compass. In man, the total respiratory surface of the lung is a number of times the surface area of the body. In the frog, it is only a small part of this. However, the frog's skin also serves as a respiratory organ. The air chambers connected with the lungs of birds serve as aids to the mechanics of respiration.

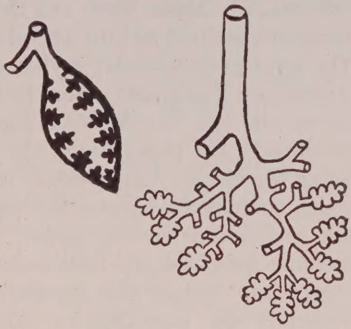

FIG. 325. — At left, diagram of lung of frog with relatively small respiratory surface; at right, part of mammal lung with relatively great respiratory surface.

The appearance of lungs in the higher Vertebrates involves a rearrangement of blood vessels, muscles, nerves and skeleton. Some of these parts are especially concerned in inspiration and expiration. The change from aquatic to terrestrial mode of life has involved active pumping or suction of air into the lungs of these forms.

C. Organs of Circulation. No special system for the conveyance of oxygen foods and wastes is needed in Protozoa, Porifera, Coelenterates, Flatworms or Roundworms. When a body cavity appears and organs develop in it and the mass of cells increases, the needs of the organs and tissues are not adequately taken care of by the old-fashioned method of transfer from cell to cell or from one cell mass to a tissue space and thence to another cell mass. This primitive method is still prevalent in the passive plant world. The term gastrovascular cavity, used in connection with Coelenterates and Flatworms, refers to the fact that the digestive tract serves the two functions of digestion and circulation. In the earthworm, the peristalsis of the body and intestine *aid* in circulating the blood. The coelomic cavity is filled with coelomic fluid which contains food material absorbed from the intestine. There are perforations in the septa. Peristalsis therefore drives the coelomic fluid back and forth and brings the body wall and internal organs into contact with digested food. The open funnels of the nephridia are immersed in this coelomic fluid. Possibly the primary function of earthworm blood is respiratory. Insects have an open or lacunar blood system. The heart is tubular and lies dorsal to the intestine. Short arterial trunks from the heart carry the blood forward into *sinuses* or spaces. Here it " circulates " about the tissues and then returns to the heart through lateral slits.

On the other hand, in Vertebrates (Fig. 326) there is a *closed blood system.* The blood, containing oxygen, food and wastes, flows in special tubes, forming one continuous interconnected system. The blood is continually leaving the heart through arteries into a system of very fine tubes, called capillaries within the tissues and returning through veins to the heart. It is open to the extent that oxygen and food solutions can pass from capillary to tissue space and waste products in the reverse direction. In Mollusks and Arthropods are found all grades between the open-system type and the closed system. In insects with tracheae, the vascular system is not concerned with delivery of air to tissues and the system is open.

The heart, arteries, veins and capillaries are structurally similar in part. Essentially tubes, they vary according to the needs. The heart is primarily a pump with valves and hence is muscular and elastic. Arteries must withstand considerable pressure and hence are thick-walled, tough, elastic and muscular. Capillaries are thin, fine, membranous-walled tubes. Veins are provided with valves so that the blood as it progresses toward the heart cannot return toward the capillaries. The membrane forming the wall of the capillaries also forms the lining of the heart, arteries and veins.

The heart of lower forms is a tube. In the embryo of Vertebrates it is at first tubular, then grows into the form of the letter "S" reversed. In Fishes (Fig. 327 — 1) it is divided into two portions. The anterior dorsal loop of the "S" widens out into a thin, saccular auricle while the posterior ventral loop of the "S" becomes the thick muscular ventricle. A valve develops between the auricle and ventricle. Venous blood from the body fills the auricle. This contracts, filling the relaxed and empty ventricle. When filled, the ventricle contracts, closing the valve to the auricle, forcibly driving the blood forward through the arterial system, aided by the muscular contractions of the arteries. The fish heart contains exclusively venous blood. In larval Amphibians *the heart is similar to that of Fishes.*

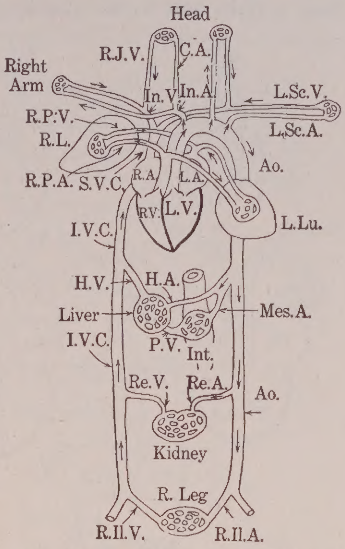

FIG. 326. — Diagram of circulation of mammal. R. A. Right auricle; R. V. Right ventricle; R. P. A. Right pulmonary artery; R. P. V. Right pulmonary vein; L. A. Left auricle; L. V. Left ventricle; Ao. Aorta; L. Sc. A. Left subclavian artery; L. Sc. V. Left subclavian vein; In. A. Innominate artery; C. A. Carotid artery; R. J. V. Right jugular vein; In. V. Innominate vein; R. L. Right lung; Mes. A. Mesenteric artery; H. A. Hepatic artery; P. V. Portal Vein; Int. Intestine; H. V. Hepatic Vein; Re. A. Renal artery; Re. V. Renal vein; R. Il. A. Right iliac artery; R. Il. V. Right iliac vein; I. V. C. Inferior vena cava; S. V. C. Superior vena cava.

But in lunged forms, like the frog (Fig. 327 — 2) the transition from gills to lungs has brought a change in the heart, for now body or venous blood and blood from the lungs is returned to different chambers of the heart. The single auricle has become divided into two, a right and a left auricle. From the body the right auricle receives the venous blood, which is poor in oxygen and rich in carbon dioxide. From the lung the left auricle receives blood which is rich in oxygen but poor in carbon dioxide. *Both* these auricles open into *one ventricle* and the complete separation of the non-aerated blood and aerated blood is not possible. In other words, Amphibia have not completely adapted themselves to land or air breathing.

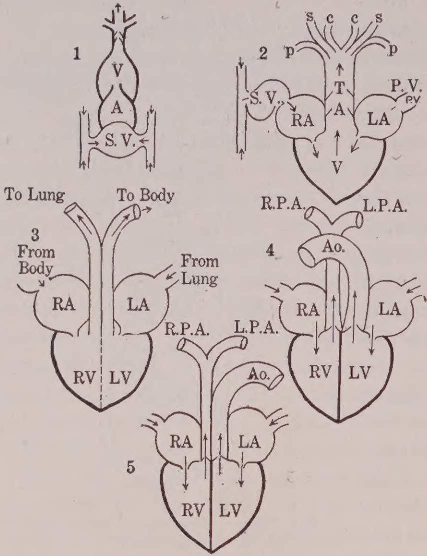

FIG. 327. — Comparative anatomy of vertebrate heart. 1. Fish; 2. Amphibian; 3. Reptile; 4. Bird; 5. Mammal. S. V. Sinus Venosus; A. Auricle; V. Ventricle; R. A. Right Auricle; R. V. Right ventricle; L. A. Left auricle; L. V. Left ventricle; R. P. A. Right pulmonary artery; Ao. Aorta; T. A. Truncus arteriosus; c-s-p, carotid, systemic and pulmonary arteries of frog. P. V. Pulmonary vein.

Reptiles are somewhat like Amphibia (Fig. 327 — 3). There are two completely separated auricles, and the single ventricle shows some advance. It contains a sort of partition, perforated and open, it is true, but dividing it, in a way, into right and left ventricular portions. It serves fairly well to regulate the currents of blood, so that non-aerated (venous) blood is directed from the right side of the ventricle to the lungs and the aerated blood from the left side of the ventricle to the body. However, strangely enough, the partition is *complete* in the *Crocodilia*, where there are *two* completely separated auricles and *two* ventricles. This is also the condition in Birds (Fig. 327 — 4) and Mammals (Fig. 327 — 5). So the heart in its evolution changes from a *tube* to a *four-chambered* organ. With the appearance of the right and left auricles and right and left ventricles, the heart has been divided into a right half and a left half. The *right heart* is associated with non-aerated blood pouring in from the body generally, and being sent to the lungs; while the *left heart* is associated with this blood returning aerated from the lungs and sending it out all over the body. The fact that so important an organ as the heart is modified in its relation to respiration indicates the importance of respiration in vertebrate life.

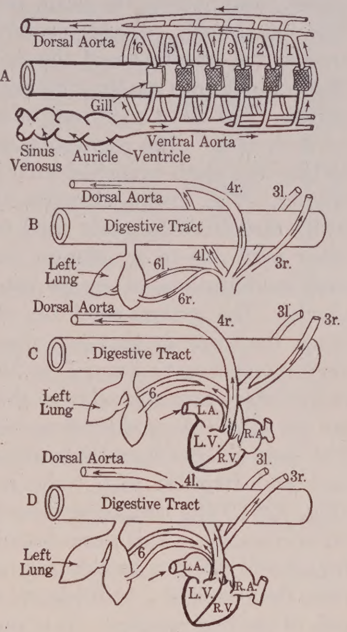
A
Dorsal Aorta
6
5
4
3
2
1
Gill
Ventral Aorta
Sinus Venosus
Auricle
Ventricle
B
Dorsal Aorta
4r.
3l.
Digestive Tract
Left Lung
6l
4l.
3r.
6r.
C
Dorsal Aorta
4r.
3l.
3r.
Digestive Tract
Left Lung
6
L.A.
L.V.
R.A.
R.V.
3l.
D
Dorsal Aorta
4l.
3r.
Digestive Tract
Left Lung
6
L.A.
L.V.
R.A.
R.V.

FIG. 328. — Comparative anatomy of aortic arches of Vertebrates.

In describing the vascular system of the dogfish (Fig. 328 *A*) and fishes in general it was stated that from the ventricle the blood was pumped forward into a vessel on the median ventral floor of the mouth. From this vessel branches pass to the gills. These are called the *afferent* branchial arteries since they carry blood to the capillaries of the gills. From these capillaries blood flows dorsally through *efferent* branchial arteries to the dorsal aorta, which has many branches for distributing the blood to various organs of the body. These sets of branchial arteries on both sides of the pharynx, extending from the ventral blood vessel to the dorsal (aorta) vessel, are known as the aortic arches. There are typically six pairs of these arches, but of special interest are four pairs which are here numbered 3, 4, 5 and 6 — number 3 being most anterior. The arrangement appears to be entirely different in Birds and Mammals. Studies in comparative anatomy, however, show a *progressive change* from what is found in the dogfish to that of the higher animals.

The arrangement in frog tadpoles is quite like that of the fish. But when metamorphosis occurs and the fish-like tadpole becomes an air-breathing frog, the following changes occur (Fig. 328 *B*). As the gills disappear, the afferent and the efferent branches unite. Remnants of the first two unite with the third branchial artery on each side, which loses its connection with the dorsal aorta and passes forward into the head, being known as the *carotid artery*. The fourth pair remains conservative, that is, each passes up around the intestine and the *two unite* to *form the dorsal aorta*. These are known as the *systemic arteries*. The fifth pair degenerates. The sixth pair bud off a branch on each, which grows *out to the lung*. The connection with the dorsal aorta degenerates, so that the sixth branchial arch is converted into the *pulmonary arteries*. The above changes illustrate change of function in which structures formerly used for one purpose are modified for other uses, due to a different mode of life. Many instances of such modifications of organs can be found both in animals and plants. The general condition of the aortic arches of reptiles is much the same as that just described for Amphibia. But it is very interesting to know that the embryo reptile first possesses rudimentary arches similar to that of fish, though of course there are no gills. A modification is found in Birds and Mammals. The main arteries from the heart are much the same as in Amphibians and Reptiles with some important differences. In Birds (Fig. 328 *C*) the carotid arteries have shifted and originate from an aortic arch. This same branch also supplies branches to the breast and wings. In the frog, arteries similar to the last arose from the systemic. In Birds, only the right branch of the systemic pair of the frog remains. It is very large and is known as the arch of the aorta. It arises from the left ventricle. There is no sign of the fifth. The sixth or pulmonary pair originate from the right ventricle.

The condition in Mammals is similar to that in Birds, with this curious difference (Fig. 328 *D*). The great aorta as it originates from the left ventricle is the *left* branch of the systemic pair of the Amphibia and Reptiles instead of the *right* as in Birds. In Birds, the great aorta turns from the heart over to the right side of the body. In Mammals it curves over to the left and then around to the backbone. In the embryos of these forms (Birds and Mammals) the early history of the vessels from the heart is fish-like, then amphibian-like, and then bird- or mammal-like. Even more remarkable is another observation. It was stated that in metamorphosis of the frog the sixth aortic arch buds off the pulmonary. For some time this artery, however, continues a connection with the dorsal aorta, but this connection later degenerates as the gill degenerates. Curiously enough this same procedure is gone through in the embryonic development of the pulmonary artery of higher forms, such as Mammals. In the vast majority of cases, the connection between this sixth arch and the dorsal aorta, although open at birth, soon closes and degenerates. But in *some* cases it fails to do so and persists on one side in the adult condition after birth. This queer anomaly of great theoretical interest is known in *human* anatomy as the "*Ductus Botalli*," and it occurs, though very rarely, in human beings, indicating the anatomical relationship of man to the lower animals.

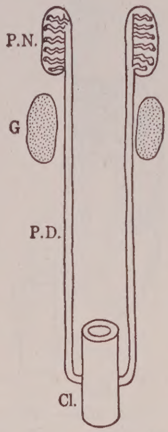

FIG. 329. — Diagram of vertebrate pronephros. PN. Pronephros; G. Gonad; P. D. Pronephric duct; Cl. Cloaca.

D. Excretory Organs. Protozoa, Porifera, and Coelenterates have no special excretory systems. Excreta are probably discharged from the free surfaces of the cells. In the flatworm there is a complicated system of tubes joining longitudinal canals which discharge wastes to the outside. Each branch tube ends internally in a flame cell, already described.

In the earthworm (Annelid) there are pairs of serially repeated nephridia. In Amphioxus a somewhat similar condition is found.

In early vertebrate embryos there appears a *Pronephros* or front kidney (Fig. 329). This consists of a series of segmentally arranged nephridial tubules each opening into the body cavity at their inner ends. The outer ends, however, do not open separately to the outside of the body as in the earthworm, but are connected to a *conducting tubule* or *segmental* or *pronephric duct* which connects posteriorly with the cloaca. In Cyclostomes, the pronephros remains throughout life, although somewhat degenerated. In some Fishes and Amphibia it is found in early stages.

Later in the embryos of Fishes and Amphibia, a second set of nephridial tubules develops toward the posterior end of the animal.

As this group of tubules develops, the first group (Pronephros) degenerates. The second kidney is called the *Mesonephros* (Fig. 330). In Elasmobranchs and some Amphibia the pronephric duct develops lengthwise into two. One of these remains as the ureter and the mesonephric tubules discharge into it. The other duct becomes the oviduct in the female. Each of the oviducts is funnel-shaped at the anterior end but opens into the cloaca at the posterior end. The new kidney is also called the *Wolffian body*, and the ureter tube is called the *Wolffian duct*, while the oviduct tube is called the *Müllerian duct.*[1] A curious condition prevails in male animals that possess a mesonephros, in that *the Müllerian duct often persists as a blind rudimentary tube.* From the testes, fine tubes, called the *vasa efferentia*, grow out connecting the testis with the *Wolffian duct*, which also *serves in the male as a sperm duct, during the breeding season.* During the remainder of the year, it is only a ureter. The mesonephros or Wolffian body is the functional kidney of Fishes and Amphibia. The adult kidney is not merely a few segmentally repeated nephridial tubules. It is a compact organ consisting of a very great many tubules, all joining larger branch ducts which in turn empty into the ureter.

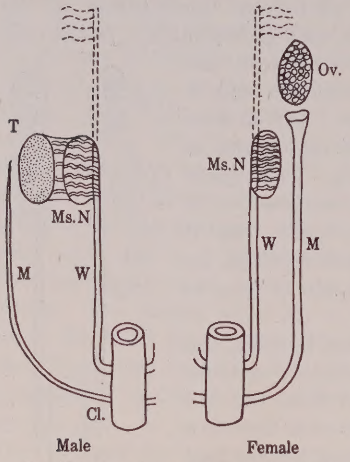

FIG. 330. — Mesonephros and related structures. Ms. N. Mesonephros; T. Testis; M. Müllerian duct; W. Wolffian duct; Ov. Ovary.

In Reptile, Bird and Mammal embryos, the pronephros first forms, then as it degenerates the mesonephros develops. Then a new third kidney forms, namely, the *Metanephros* (Fig. 331). It is posterior to the mesonephros. Moreover, it develops a new functional discharging tube, the ureter. In the meantime, the mesonephros gradually disappears. The metanephros remains as the functional adult kidney of Reptiles, Birds and Mammals.

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[1] In many Vertebrates the Müllerian duct develops from tissues near the Wolffian duct.

The Müllerian duct of the mesonephric system persists, however, as the functional oviduct of females. The vasa efferentia of the testis pass into the Wolffian duct, which now performs the *exclusive duty* of a *sperm duct* or *vas deferens.* In early embryonic tubules of the pro- and mesonephros the outer ends open by ciliated funnels into the body cavity, as in the earthworm. This end is the nephridial mouth or *nephrostome.* In the mesonephros, a small cup-shaped cavity develops near the nephrostome. This becomes filled with capillaries, and is known as a *Malpighian body.* Indications of nephrostomes are still present in the frog's kidney. They appear on the surface as pits. But they do not form in the metanephros. In this kidney the tubules are supplied entirely by the blood and terminate in Malpighian bodies (Fig. 343).

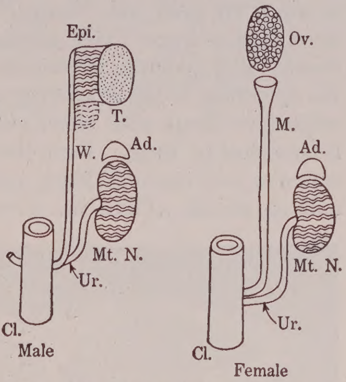


FIG. 331. — Metanephros and related structures. Mt. N. Metanephros; Ur. Ureter; Ad. Adrenal; Epi. Epididymis; T. Testis; Ov. Ovary; W. Wolffian duct; M. Müllerian duct; Cl. Cloaca.

II. Comparative Anatomy of Organs of Adjustment

Notwithstanding the fact that the organism is a complete whole whose parts are interdependent, the foregoing systems of organs are more immediately concerned in keeping the cells supplied with metabolic material and in removing wastes. Life is one continual process of adjustment to varying environmental conditions. Moreover, food and security from possible enemies must be obtained. Certain systems of organs seem to be concerned with this part of life. They are the *sensory, nervous* and *muscular* systems. Locomotion in higher forms like Vertebrates is often rapid, sustained, covering large distances and consuming much energy. In these cases muscles are associated with skeletons. Moreover, the surface of the body is covered with skin that protects internal organs. In discussing organs of adjustment skin and skeleton should be included.

A. Skin or External Covering. In some Protozoa, the external superficial protoplasm is more dense than that inside and from it may extend cilia or flagella. In Coelenterates, the ectoderm is covered with a non-cellular thin coat — the cuticle. In flatworms there is a somewhat similar but firm cuticle and in some parasitic roundworms it is somewhat thickened and hard. In Annelids it is thin, as in the active earthworm. The shell of Mollusca and the chitinous exoskeleton of the Arthropoda are recalled. In Vertebrates skin is a special, complicated tissue composed of two main layers: (*a*) *epidermis*, formed of several layers of cells most of which are dead and "horny," called the stratum corneum, derived from a deeper living germinating layer, the *stratum germinativum*. The epidermis contains no blood vessels or nerves. Below the epidermis is the (*b*) *dermis* or lower skin, which is a special connective tissue with blood vessels and nerves. The epidermis is nourished by these. From the *epidermis* are derived some types of scales and feathers, hairs, nails, claws, and mammary, sweat and oil glands. From the *dermis* is derived the scales of most fishes, bony plates of Crocodilia, and of such Mammals as the armadillo and some of the bones of the skull. The skin contains important sense organs of touch, pain and temperature. It develops also sweat, oil and mammary glands.

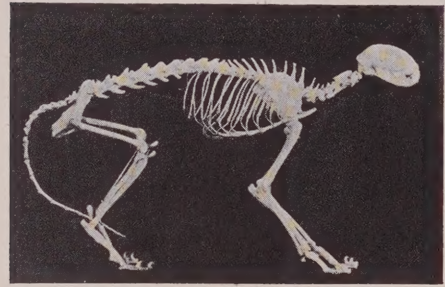


FIG. 332.—Skeleton of cat. Axial skeleton—skull and spinal column. Appendicular skeleton—Shoulder girdle and fore limb; pelvic girdle and hind limb.

B. Skeleton. A supporting framework of a sort occurs in radiolarian Protozoa and the Vertebrates, although many intervening forms lack it. In Arthropods there is a horny or chitinous outside skeleton, somewhat analogous to the armor of old-time knights. To the inner surface of these parts are attached muscles which connect adjoining parts. In Vertebrates there is an endoskeleton of cartilage in lower forms; and of cartilage and bone in such intermediate forms as Amphibia, but almost entirely of bone in Birds and Mammals.

The skeleton of the Vertebrate consists of an *axial* and an *appendicular* part (Fig. 332). The first (Fig. 333) consists of the skull and vertebral column. The appendicular part consists of the front limbs and pectoral girdle, and the hind limbs and pelvic girdle.

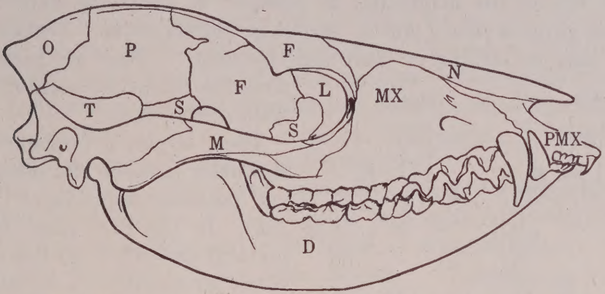
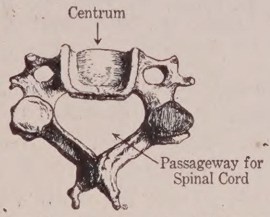
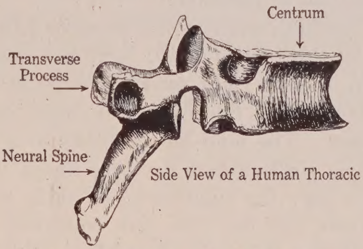


Fig. 333. — Side view skull of opossum. Cranial bones shown are F. Frontal; S. Sphenoid; P. Parietal; O. Occipital; T. Temporal. Facial bones shown are M. Malar; L. Lachrymal; MX. Maxillary; PMX. Premaxillary; N. Nasal. Lower jaw is (D) Dentary or Mandibular.

The mammalian skull (Fig. 333) consists of the *cranium* and *face*. The cranium incloses the brain, while the face forms the nostrils, mouth, jaws, etc. Some of the bones of the cranium frequently found are frontals, parietals, occipital, temporals, ethmoid and sphenoid. The face is formed by the nasals, lachrymals, malars, palatines, maxillaries, pre-maxillaries and vomers. The lower jaw is the dentary or mandibular. There is considerable variation in the bones of the skull, but the similarities are as notable as the differences.



Face View of a Human Cervical Vertebra



Side View of a Human Thoracic Vertebra

Fig. 334. — Human vertebrae.

The vertebral column, the backbone of the Vertebrate, is composed of vertebrae. A vertebra (Fig. 334) possesses a supporting centrum, the neural arch inclosing the spinal cord, the neural spine to which some muscles of the back are attached and transverse processes to which ribs may be attached. Five kinds of vertebrae are found in Mammals, all modifications of a generalized type, namely, 1. *cervical*, forming the neck; 2. *thoracic*, which always have ribs in the mammals; 3. *lumbar;* 4. *sacral*, to which the pelvic girdle is joined and 5. *caudal*, or tail vertebrae. Vertebrate ribs may be lacking or there may be many. They are present, wherever needed, to support the walls of the trunk.

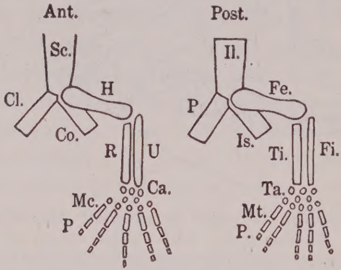


FIG. 335. — Structure of appendicular skeleton of (land) Vertebrates. Anterior — Sc. Scapula; Cl. Clavicle; Co. coracoid; H. Humerus; R. Radius; U. Ulna; Ca. Carpals; Mc. Metacarpals; P. Phalanges. Posterior — Il. Ileum; P. Pubis; Is. Ischium; Fe. Femur; Ti. Tibia; Fi. Fibula; Ta. Tarsals; Mt. Metatarsals; P. Phalanges.

There is also a fundamental similarity between the anterior and posterior appendages (Fig. 335). In the first place both pectoral and pelvic girdles consist of three parts — a *dorsal element*, the *scapula* in the pectoral girdle and the *ileum* in the pelvic girdle. The scapula is joined indirectly by ligaments and muscles to the axial skeleton, while the ilium is firmly united directly to sacral vertebrae. Each girdle has two processes extending ventrally. In the pectoral girdle, the *procoracoid*, and in the pelvic, the *pubis*, extend down and forward, while in the pectoral, the *coracoid*, and in the pelvic, the *ischium*, extend down and backwards. The procoracoid is represented by cartilage and it is replaced in higher forms by a bony clavicle. There are many departures from this underlying simple type plan and variation in structure appears to be related to variations in function.

The forelimb consists of a *humerus* joined to the pectoral girdle, where its three parts meet; next of a *radius* and *ulna* forming the forearm, then of eight *carpal* or wrist bones, of five *metacarpal* or hand bones, and five fingers or *digits*, each composed of several phalanges. The hind limb consists of a *femur* or thigh joined to the pelvic girdle, where its three bones meet; then the *tibia* and *fibula* or leg; the eight *tarsal* or ankle bones; five *metatarsals* or foot bones, and five toes each composed of phalanges. In forms above Fishes, this appendage plan prevails, although there are all sorts of modifications of it since the appendages function in a great variety of ways.

C. Muscles. The skull protects the brain, and the backbone and ribs protect visceral organs. But more than this, the backbone is a rigid axis to which levers are attached. These levers are moved by skeletal muscles in limbed forms for use in locomotion. In the tubular earthworm's body wall and likewise in its intestine there are longitudinal and circular muscles. The contraction of the body wall and of the intestine is peristaltic, which has already been explained. It is the common movement of intestines, oviducts, ureters and arteries of Vertebrates.

The Amphioxus body wall possesses a series of segmentally repeated muscle masses or *myotomes.* These are seen also in Fishes and in lower Amphibia and in the embryos of higher forms. They are more primitive in forms without limbs. Their successive contraction on one side and relaxation on the other moves the body sidewise as in the movements of the tail in swimming. Skeletal muscles of the adult develop from portions of the embryonic myotomes. When limbs are introduced, the segmentally arranged embryonic portions in the neighborhood of the limbs grow out to the girdle and limb bones and form the special muscles of those organs. With the increasing modifications in the limbs and with changes in their use, the modifications in the muscles become more complex. The fore and hind limbs of Necturus are small and quite similar, and the muscles of each are similar. In the frog, there are short, weak, front limbs and large, strong, hind limbs. The muscle outfit of each is extremely different. The muscle system of the front limb and hind limb of a bird are very different. One does not find any close similarity between the musculature of the front limbs of a dog, horse, bat or chimpanzee. Muscles are plastic structures, far more plastic than bone, and to the comparative anatomist even bone is not regarded as unchangeable. In spite of the extreme modifications of muscles in different types, the trained myologist is satisfied as to a simple general underlying plan. Skeletal muscles usually have a contractile portion called the *belly* and two ends terminating in inelastic *tendons* attached to bones. The muscle has a proximal end, attached to some part toward the central axis. This is the *origin* of the muscle. The outer distal end is the *insertion.* The *origin* is usually fastened to a support, and the muscle lifts a lever to which it is *inserted.*

D. Nervous System. First indications of special fibers which conduct impulses have been noted in certain Protozoa, such as Euplotes. Definite nerve cells are found in Coelenterates. Neurons and nerves are present in all higher forms. Annelids show a centralized nervous system with ventral nerve cord, segmental ganglia, dorsal brain and peripheral nerves. Arthropods with their condensed bodies show a concentration of this same general plan in the large cerebral and thoracic ganglia. Both have a ventral nerve cord and an anterior nerve ring about the anterior end of the intestine. The nervous system reaches its highest development in the Vertebrates, where it is organized into (*a*) *central nervous system* of brain and spinal cord, (*b*) *peripheral system* of cranial and spinal nerves and (*c*) *sympathetic system.* In the study of the Vertebrates a general increase in the size and the importance of the cerebral hemispheres (Fig. 336) is seen as we pass from Elasmobranchs to Mammals, culminating in the human brain, where it is relatively enormous and richly fissured and convoluted, thus making the *cortex* (or rind) of greater area than the cranial space it occupies. The olfactory lobes and optic lobes decrease relatively in size and importance, while the increase in the cerebellum is secondary only to that of the cerebrum. Between the cerebral hemispheres and optic lobes is the between-brain or *diencephalon.* Projecting from this on the ventral side toward the roof of the

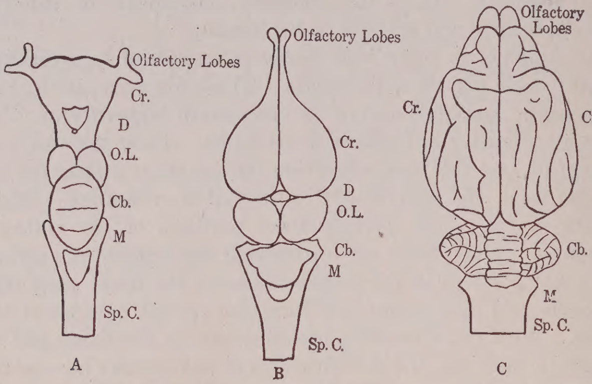


FIG. 336. — Dorsal view of brain of A.— Dogfish; B. — Alligator; C. — Dog (after Ziegler models); Cr. Cerebrum; D. Diencephalon; O. L. Optic lobes; Cb. Cerebellum; M. Medulla; Sp. C. Spinal cord.

mouth is an outgrowth. Here is attached an important ductless gland, the *pituitary.* Also from the dorsal surface a stalk-like structure extends upward, known as the *pineal gland.* In all Vertebrates, the five parts of the brain are plainly discernible. The cranial nerves of all are similar in location, structure and function, and this is true of the spinal cord and spinal nerves. Analysis of the nervous system shows that it is composed of complex cells of varying shapes called neurons. Proper connections and organizations of these make possible the carrying out of adjustments. Operations of internal body organs are carried out with the help of the sympathetic system. The part played by hormones is discussed on page 434. Some nerves contain only afferent fibers. Examples are the following *cranial nerves:* first or olfactory, second or optic and eighth or auditory. The third, fourth and sixth *cranial nerves* are purely *motor* since they carry only motor impulses to the muscles of the eye. The fifth, seventh, ninth and tenth *cranial nerves* resemble spinal nerves in that they contain both sensory and motor fibers. Sir Charles Bell in 1824 first proved the existence of sensory and motor pathways in nerves. He remarked that "they do not in any case interfere with or partake of each other's influence."

E. Sense Organs. Sense organs, developed from ectoderm, are cellular structures whose function is to receive stimuli from the external medium.

References to the sensory organs of lower groups have been made. The earthworm does not have well-recognized special sense organs of touch, smell, or sight and yet is sensitive to all these types of stimuli. Probably insects react to ranges of stimuli beyond our knowledge. Arthropods and Mollusks have well-developed sense organs. The sense organ of smell of

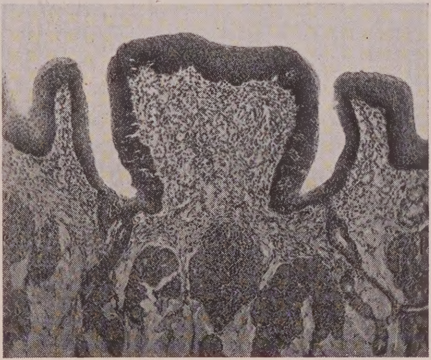


FIG. 337 *A.* — Photomicrograph of section of a vallate papilla of tongue. Sensory cells of taste are located in special organs (taste buds) on side walls of the papilla. (Photo by Cooper.)

Mammals consists of cells located in membranes in the nose. These cells are connected by nerves to the brain. There are only nasal sacs in Fishes, while in higher forms they open by passageways into the pharynx and take on a double function, assisting also in respiration. The skin contains many sensory organs of touch, pressure, temperature and pain. Sensory organs occur in muscles and are stimulated when the muscle changes its form, thus giving an idea of muscular movement. Special cells in the taste buds of the tongue are stimulated by certain substances in food and drink (Fig. 337 *A*).

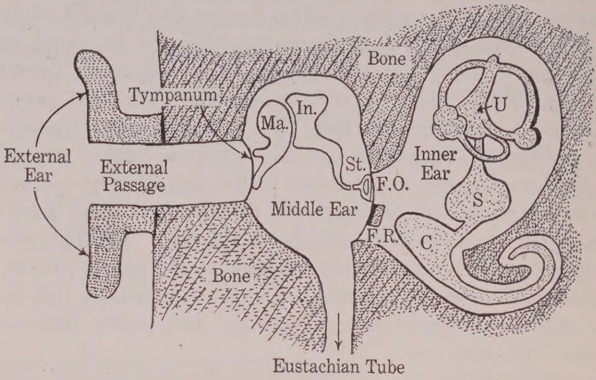


FIG. 337 *B*. — Structure of mammalian ear. Ma. Malleus; In. Incus; St. Stapes; F. O. Fenestra ovalis; F. R. Fenestra rotunda; U. Utriculus; S. Sacculus; C. Cochlea.

The ear develops as a pit in the ectoderm. Ears like this are found in Invertebrates. In the Vertebrates this pit becomes detached from the surface and forms the internal ear surrounded by a bone of the skull (Fig. 337 *B*). Inside of the skeletal surroundings it occurs as a membranous sac filled with liquid and becomes very complicated. It forms two sacs known as the *sacculus* and *utriculus*. From the sacculus develops, in higher forms, the spirally tapering cochlea containing sensory cells stimulated indirectly by sound waves outside the body. The sensory cells of the cochlea are connected by certain fibers of the eighth cranial nerve to the brain. From the utriculus there develops the semicircular canals. One of these is horizontal, the other two are vertical and at about a right angle to the first and to each other.

These canals are membranous tubes and each contains an enlargement called an *ampulla*, where are the sensory cells which are stimulated by changes in the position of the head (or body). Information borne to the brain from these organs over other neurons of the eighth nerve gives the animal knowledge of its special position. The cochlea is the sense organ of *hearing* and the semicircular canals of *equilibrium*. As long as animals are immersed in water, sound is of minor importance, but not so in the case of equilibrium. Impulses to the ear of fishes must come through the skull.

The spiracular cleft of Elasmobranchs is homologous with the tympanic cavity or middle ear, between the surface of the skull and the inner ear of land forms. In the land Vertebrate the Eustachian tube, from the mouth to the mid-ear, is a part of it. Between the inner and the middle ear a little window, *fenestra vestibuli* or *fenestra ovalis*, develops. Stretched across the external opening of the middle ear is the ear drum or tympanic membrane. This is flush with the surface of the head in Amphibia. In higher forms it lies at the inner end of a small passageway — the external canal. Surrounding its external opening in many Mammals is the external ear. Stretching across the middle ear from tympanum to fenestra ovalis in Amphibia, is a single little bone, the *columella*. Sound waves in air vibrate the tympanum. These vibrations are conveyed by the columella to the inner ear drum stretched across the fenestra vestibuli. Vibrations in this, set up vibrations in the liquid in the cochlea which stimulate the sensory cells of hearing. In Mammals, the columella is replaced by a chain of three little levers of bone: *outer, malleus; middle, incus; inner, stapes*, by which the vibrations are more effectively transmitted. These structures are special modifications of parts used for other purposes in lower Vertebrates.

Sight. Special sense organs of vision appear as animals become more specialized. The eyes of all Vertebrates are surprisingly similar in structure. In cave animals and deep-sea forms, the eye is degenerate. The eye is a hollow globe (Fig. 338) or rather parts of two globes. The wall is of tough, resistant material. There is an outer *sclerotic* coat. It has a transparent front, known as the *cornea*. Inside the sclerotic is the vascular and pigmented *choroid* coat. In front, it does not lie close to the cornea but close to the front of the lens and contains an aperture, the *pupil*. The disc around the pupil is called the *iris*. The third or inner coat of the eyeball is the *retina* which contains the special sensory cells of vision. These are connected to the brain by the nerve cells of the optic nerve. The lens is located just behind the iris and is biconvex and transparent. It is held in place to the choroid coat by the suspensory ligament and, unlike a camera lens, its convexity can be changed and so adjust the eye to different focal distances automatically. Between the lens and cornea is fluid aqueous humor and behind the lens is the thicker vitreous humor. Light waves, reflected from external objects, pass through the lens, forming images, and stimulate sensory cells in the retina behind it. Impulses are then carried over the optic nerve to the visual center in the brain.

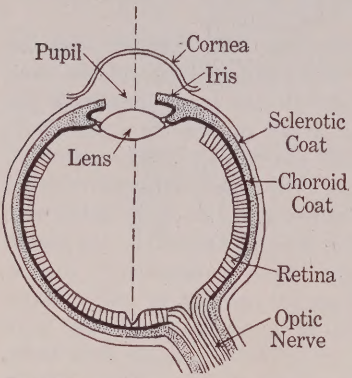


FIG. 338. — Diagram showing anatomy of vertebrate eye.

The eye is moved by six muscles in each eye which raise the eyes, lower them, turn them to the left, to the right, or roll them. Usually these muscles work harmoniously. It is not necessary to dissect a *human* eye to get a general idea of its structure. The eye of the *ox* or the *dogfish* will give about the same information. In land Vertebrates, lachrymal glands near the eye keep the eyeball moist and clean with their secretions.

The living Protozoan successfully adjusts itself to its changing world. The Amoeba exhibits but few structures enabling it to accomplish this. Some Protozoa however possess intracellular specialized structures. As we study higher and higher forms we note an increase in the complexity of special organs. Insects are highly organized animals, but a study of the comparative anatomy of the various classes of Vertebrates reveals evidence of evolution of greater specialization. The comparative anatomy of any taxonomic group reveals evidence of a type plan of structure common to all members of the group and this is interpreted as indication of common ancestry.

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CHAPTER XXII

METHODS AND ORGANS OF REPRODUCTION IN ANIMALS

Introduction. Reproduction in plants is chiefly an alternation between *sexual* and *asexual* generations. Plants also reproduce by fission, by spores, by buds and by cuttings involving regeneration. On the whole, all of these methods are employed by animals, but the prevailing method of reproduction in higher animals is sexual.

Fission. In this case, the body of the mother cell divides into two daughter cells each of which grows to maturity when the process is repeated. The parent animal of course disappears. The new and mature daughters are new animals. Fission occurs in Protozoa. New generations of Protozoa may occur from six to twenty-four hours apart.

Sporulation. This is common in the Sporozoa, but is only part of the life cycle. A Sporozoan encysts, *i.e.*, the cell wall forms a hard, thick wall. The nucleus and cytoplasm divide and subdivide many times, forming many small cells, sporozoites, and these by multiple fission, or sporulation, eventually form male and female gametes which, on fusing, form a cell (*zygote*), which in time will produce sporozoites again. Sporulation or asexual reproduction is associated with sexual reproduction in an alternation of generations. The life cycle of parasitic flatworms, such as liverflukes, involves a succession of asexual stages *suggestive* of sporulation.

Budding. The bud is a small outgrowth of protoplasm which grows into a form like the parent. In some forms it separates from the parent and leads a free life, as illustrated by young Hydras. Budding rarely occurs in Protozoa. It is more common in other Invertebrates. The hydroids, like Obelia, are formed in this way; so are corals and the medusoids of hydroid colonies. Some worms, indeed, reproduce by budding. The process is present also in the tunicate group of the Chordata. Sometimes internal buds are formed. This is found in fresh-water sponges and some higher forms allied with the Annelids.

The above are examples of asexual reproduction and gametes are not involved. Asexual reproduction does not occur in the Nemathelminthes, Echinodermata, Mollusca, Arthropoda or Vertebrata. It is more usual in lower forms. Since this is true of lower plants also, asexual reproduction may have been the first method which developed in living things. Asexual reproduction tends toward the continuation of the same forms and so suggests the idea that evolution would never have proceeded very far, had this been the sole method of reproduction.

Sexual Reproduction. In sexual reproduction the new individual develops from a single cell (zygote) formed by the fusion of two gamete cells. If of the same size, they are called *isogametes;* when of different sizes, *heterogametes,* in which case one is smaller and more active, called a *microgamete* in Protozoa, or sperm and *spermatozoan* in Metazoa; the other gamete is larger and passive and is called a megagamete or macrogamete in Protozoa, egg or *ovum* in Metazoa. In flagellate Protozoa, the Mastigophora, are found cases of fusion (or fertilization) of isogametes or heterogametes. Many instances of union between microgametes and megagametes occur in Sporozoa.

In the Infusoria occurs a specialized form of sexual reproduction, *i.e.*, conjugation.

In Metazoan animals, sperm and eggs are called *germ cells.* These are produced by special glands called *gonads*, the ovary of the female producing eggs and the testis of the male producing sperm. These glands are set apart from the other organs to produce eggs and sperm. The germ cells take no part in carrying out the functions of metabolism or adjustment of the organism as a whole. And yet the gonads are constantly in vital relation to all other organs and metabolism and adjustment of a sort occur in them. The blood which flows through other organs flows through them. Material for the protoplasm of new germ cells or somatic cells comes from substances furnished by the blood. Sperm and eggs are in a sense generalized cells — different from the special cells which compose the other parts of the body, such as nerve and muscle cells. United (*i.e.*, egg and sperm), they have the power to form a new individual.

Parthenogenesis. There are some exceptions to this rule. Drone bees develop from unfertilized eggs laid by the queen. In the Aphids, females develop from unfertilized eggs. This type of reproduction is known as *parthenogenesis*, *i.e.*, generation of a new individual from part of the parent. Its relation to budding is obvious.

It is a type of reproduction in which eggs develop without fertilization.

Artificial parthenogenesis is the experimental production of certain animals from their eggs alone and without sperm, although they normally reproduce from eggs and sperm. The eggs are treated with various physical and chemical agents such as immersion in concentrated or diluted sea water for a short time, or with chloroform, ether, alcohol, toluol, saponin, salts or bases and also by shaking the eggs or pricking them.

Alternation of generations is not the rule, but occurs among the Sporozoa, Hydroids, Flatworms, possibly among a few marine Annelids and in some Insects. For example, insects, which are parthenogenetic, interpolate a bisexual phase at some time. The female Aphids parthenogenetically produce female broods all summer. In the fall males and females appear. These males fertilize the eggs of females. The eggs have hard shells which resist the cold of winter. From them females alone are hatched out in the spring. These again produce parthenogenetically until autumn.

Paedogenesis. In certain animals the immature and undeveloped can reproduce sexually. Thus in a certain fly, Miastor, ova develop larvae parthenogenetically. The larvae escape from the parent and reproduce in a similar fashion. After several generations the larvae pupate, and reproduce sexually as adults. The Axolotl, an Amphibian, has been known to reproduce sexually in the larval stage if prevented from maturing on land. The adult form is Ambystoma. Paedogenesis, parthenogenesis and sporulation bring about a tremendous production of offspring which insures the continuance of the species even though the chances of survival are limited.

Relation of Sexual Reproduction to Evolution. There may be a question as to why sex arose when reproduction can take place without it. Sexual reproduction insures variation in new individuals. The chances are that the protoplasm of any sperm is not the same as that of the egg, and so in sexual reproduction there is the combination of different protoplasms. The resulting individual is unique. No other exactly similar individual ever existed before. Thus the chance production of some organisms more fitted to the environment is possible. The importance of variation is indicated in the discussion of heredity. Its relation to evolution is discussed later.

Reproductive Organs. The establishment of special sex cells occurs even in the Protozoa. It appears in Volvox in which there are no special organs for metabolism or adjustment. It is also known, that *very early* in embryonic history of Metazoa certain cells are set aside to form sex glands. These facts indicate that sexual reproduction is very old in the history of living things, that the continuance of the species is as important as are breathing, digestion and locomotion to the individual. Animals live to reproduce. In some animals, the gonads grow and become functional only during that period of the year when conditions are most favorable for breeding.

Monoecious and Dioecious. Both types of sex glands often appear in the same animal. Such an animal is called *monoecious*, or *hermaphroditic*. Hermaphroditism is more often the rule than not in the lower animals. For example, it is noted in Sponges, Coelenterates, Flatworms, Roundworms and Annelids. It continues to be present in other groups, although it is rare in the higher Vertebrates. Sometimes the same gland normally functions as a testis and ovary, that is, the animal possesses an hermaphrodite gonad. This is the case in certain land snails.

Self-fertilization, or physiological hermaphroditism, is more rare than anatomical hermaphroditism. It occurs in tapeworms (Fig. 152). The monoecious animal *usually* first functions as a male, then later as a female or vice versa. Most Tunicates first produce eggs and then when this period passes, their testes become functional and they produce sperm. In the hag-fish, Myxine, the animal first produces sperm, then later eggs. In this way the eggs from any one animal are not likely to be fertilized by the sperm from that animal. There is strong evidence to indicate that hermaphroditism was the primitive condition, but the separate sexed or dioecious condition is the rule in higher forms.

Gonads and Gonaducts. While sex glands (ovary and testis) are usually present in multicellular animals, yet special ducts for conveying their products from the animal are not always necessary and may be absent. For example, in Hydra simple sex organs are found on the surface of the body and sperm escape directly from the testis into the sea water. In the jellyfish, on the other hand, sex glands occur in the walls of the gastro-vascular cavity, and sperm and eggs pass into this cavity and thence out. Gonaducts of one kind or another for conveyance of sperm and eggs are found in Flatworms, Roundworms, Annelids, Mollusks, Arthropods and Vertebrates. Where the gonads are developed from tissues lining the body cavity, their products (eggs and sperm) are first discharged into the body cavity, and then escape. They must be discharged from this by one kind of duct or another. In many female Teleosts the ovary lies in a sac which extends to the cloaca. In Cyclostomes the eggs and sperm pass into the body cavity and from this through pores into the cloaca.

Usually ducts associated embryologically or otherwise with excretion are used. The oviduct in some Vertebrates originated as a separation from a primitive ureter. In male Fishes and Amphibia the ureter became connected with the testis and serves a double purpose. In the Amniota (Reptiles, Birds and Mammals) it is no longer a ureter but functions wholly as a vas deferens.

Oviparous and Viviparous. In lower forms, fertilization of eggs occurs normally outside the body. In most aquatic animals — Coelenterates, Echinoderms, Fishes and Amphibia — eggs are discharged into the water, sperm are shed near them and are attracted to the eggs. In land animals, eggs and sperm would easily be destroyed if exposed to the air for long, so sperm are introduced into the oviducts of the female. Internal fertilization is the rule in Elasmobranchs, which are more primitive than Teleosts in which fertilization usually is external. Internal fertilization is also the rule in Arthropods, Reptiles, Birds and Mammals. In most Elasmobranchs, in Reptiles, Birds and Insects fertilized eggs are discharged from the body. Such animals are said to be *oviparous*. The eggs of Birds, Reptiles, Amphibia and Fishes have stored up in them considerable quantities of food called yolk, which is formed by the ovary. The oviduct secretes a surrounding mass of white or albumen and also shell membrane and a shell in Reptiles and Birds and a group of Mammals. The egg case of the skate is horny while those of turtle and hen are calcareous.

Although many Vertebrates are *oviparous,* yet some of these classes have representatives in which the young are developed within the body of the mother, *i.e.,* are *viviparous.* Such cases are found among sharks, Teleosts, tailed Amphibia and Reptiles. In all Mammals with the exception of the Monotremes, development occurs within the body of the mother. In the case of oviparity, yolk is produced by the ovary, but it is also true that in viviparous Mammals, ovarian hormone is greatly concerned in developing the placental system of foetal nourishment. The latter is a further modification of the form of yolk feeding. In Reptiles, Birds and Mammals the embryo is kept more quiescent, which condition is more favorable for development and growth. The beginning of independent life is delayed and the period of greatest mortality is safely passed. The chance of survival is thus increased, and this is especially true of the placental Mammals, in which the feeding and the care of offspring by the mother is of further benefit to the individual. It is now known that milk contains important vitamins.

Intromittent Organs and Uterus. To secure the safe transfer of sperm to the oviducts of the female, organs of intromission appear, such as the claspers of the male dogfish. Special structures called penes are found in certain Reptiles and Birds; the penis of higher Mammals is a specialized development of these. The oviducts of Vertebrates remain separate tubes, terminating in the cloaca in Elasmobranchs, Amphibia, Reptiles and Birds and Monotreme Mammals. Examination of the Placental Mammals shows that, beginning posteriorly, there is a fusion of the oviducts to form a common vaginal chamber for the reception of sperm, and in apes and man a single uterus or womb in which the eggs will develop. In Carnivora, the uterine portions of the oviducts are still quite separate but partly fused and young develop in each horn. In the mouse and elephant they are separate.

Conclusion. The essential fact in all types of reproduction in plants and animals is this, that a small mass of protoplasm, a cell, separated from the body of one organism (in asexual reproduction) or formed from two (in sexual reproduction) has the power of developing into another organism like the parent or parents. A sperm or egg of itself is usually incomplete. In sexual reproduction animals develop from a single cell. This single cell, a complete whole, is present after the egg cell and sperm cell unite, and all the structures, organs, devices, secondary sex organs, sex antics of animals and sex emotions are but part of the machinery concerned in bringing about the formation of a fertilized egg, *i.e.*, union of egg and sperm. And for what? So that the race may continue! And yet race continuance is not the primary consideration of the individual animal for, as a rule, the first consideration seems to be self-preservation. Hunger and thirst are examples of primary sensations, but the reproductive instinct closely follows these. It should be remembered that reproduction has produced the animal that has these instincts. Of the three great groups of functions comprising the physiological life, those of metabolism and adjustment are not only primary but preessential to reproduction. Many examples could be cited indicating that the third is the goal of the first two. The queen bee dies when her reproductive activity ceases. The life of the adult May fly is limited to a few hours devoted to reproductive activity. Numberless instances are recorded of maternal sacrifices among Mammals in an attempt to preserve the life of offspring, so much so that these words, paraphrased from those of Tennyson, are indeed appropriate: "So careless of the individual, so careful of the type."

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CHAPTER XXIII

PHYSIOLOGY

Introduction. It has been pointed out that what is called life consists of a characteristically complex series of changes exhibited by a certain kind of organization of chemical elements and compounds, called protoplasm. The preceding pages contain brief descriptions of different types of organizations considered chiefly from the morphological point of view. As each group was taken up, general statements with regard to physiological processes were made. For convenience these functions were divided into three groups: first: those of *metabolism;* second: processes of *adjustment;* third: processes of *reproduction.*

In single-celled Protozoa all these processes are carried out by one cell. Moreover, it is altogether likely that more than one process is going on simultaneously in any single Protozoan.

The evolution of the Metazoa, from the simpler types to the highest, involved the gradual building up of special groups of cells, tissues, organs or organ systems for the more efficient carrying out of particular functions. Yet all the functions are necessarily displayed by both Protozoa and Metazoa.

Physiology of Specialized Cells. (See Chapter XVIII, Part III.) The *chief function* of a muscle cell is to contract. It does this better than any other type of cell. But at the same time it is sensitive and can also conduct; it respires, excretes and circulates. Many different chemical processes occur in every cell. It must not be forgotten however that, as differentiation increases in the evolution of specialized types, one type of cell, now being a specialist in one type of work, does not perform other types of work but only its own particular life function.

The import of all this is, that if a general science of physiology of receptors is desired, then one should study the most specialized organs of sense where the receptive function exists in its purest form. And so with contraction, conduction, excretion, etc. In the higher Vertebrates with their special systems of organs, functions are segregated, there is a natural sorting out, enabling us to study special functions. More is known of the physiology of the Vertebrates and therefore a brief summary is presented here of physiological processes in forms more closely related to man.

FUNCTIONS OF METABOLISM

Cell metabolism refers to the totality of chemical activities which occur *in cells*. Metabolism takes place in *every cell;* in egg cells, nerve cells, muscle cells, in stomach and kidney cells and those of all other organs.

Our classification of functions is a matter of convenience. What we term "functions of metabolism" are those more intimately concerned in *preparing* and furnishing to cells, the materials for cell metabolism and also getting rid of the wastes of cell metabolism.

Digestion (Fig. 339). Animals ingest substances from which, by the processes of metabolism, they will obtain materials for the repair of cell and tissue; for growth; for reproduction and energy by which vital processes can be maintained. We call these substances foods. They are partly inorganic, *i.e.*, water and inorganic salts, and partly organic, *i.e.*, proteins, carbohydrates, fats, oils and vitamins. The nature of proteins, carbohydrates and fats has already been explained. Vitamins are discussed later.

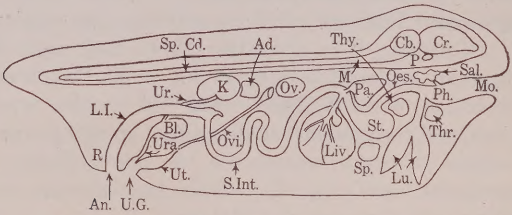

FIG. 339. — Diagram of digestive tract and other organs of a female mammal. Cr. Cerebrum; Cb. Cerebellum; P. Pituitary gland; M. Medulla; Sp. Cd. Spinal cord; Mo. Mouth; Ph. Pharynx; Sal. Salivary glands; Oes. Oesophagus; Thr. Thyroid; Lu. Lungs; Thy. Thymus; St. Stomach; Sp. Spleen; Pa. Pancreas; Liv. Liver; S. Int. Small Intestine; L. I. Large Intestine; R. Rectum; An. Anus; Ov. Ovary; Ovi. Oviduct; Ut. Uterus; Ad. Adrenal; K. Kidney; Ur. Ureter; Bl. Bladder; Ura. Urethra; U. G. Urino-genital sinus.

Digestion changes complex compounds taken in, as food, into simpler compounds suitable for use by the various cells of the body. Proteins are changed to amino-acids; carbohydrates to monosaccharids and fats to fatty acids and glycerine. The useful parts of the food are separated from the useless, and for purposes of circulation, the useful constituents are rendered soluble.

In most Invertebrates and in Vertebrates, foods are ingested and pass into and along the intestinal tract into which digestive glands (or cells) secrete enzymes which accomplish the simplification of the complex compounds referred to above. The movement of the food mass is brought about by the contraction of smooth muscle cells in the wall of the alimentary tract (peristalsis). Complicated and orderly mechanisms are concerned in the process.

Mouth. Food does not remain long in the mouth cavity of many vertebrates, passing quickly down the oesophagus into the stomach. Man normally masticates his food, changing the pieces to a mass of finely divided particles mixed with fluid. Saliva, derived from the salivary glands, is mostly (99.5%) water, but contains inorganic salts, a protein compound called mucin and in some animals, an enzyme called ptyalin which partially digests starch. There are three main pairs of salivary glands. First, parotids (near the ear); second, submaxillaries and third, sublinguals. From the salivary glands, secretions pass into the mouth cavity, where they are mixed with food. The production of saliva depends on stimuli, such as tasting, smelling, seeing or even thinking of food. In some emotional states, salivary secretion is inhibited.

From the mouth cavity the food is passed along the oesophagus and by *its* contractions to the stomach.

Stomach. Layers of smooth muscle in the walls of the stomach make possible a series of peculiar peristaltic movements, following each other at the rate of three or four per minute. At the same time it persistently accommodates itself to the amount of food inside. The larger left end (cardiac portion or fundus) maintains a continuous pressure on the food all the time, while peristaltic movements at the right end slowly churn the food. The movements persist after connections with the nervous system are cut. And yet although the movements originate independently of nerve impulses, they may be modified through nerve reactions. If impulses pass over fibers of the vagus (tenth cranial nerve), violent and painful reactions may take place. Certain emotional states may produce this result. Impulses over sympathetic nerves to the stomach cause an inhibition of stomach movements.

The wall of the stomach contains glands (Fig. 340) which secrete gastric juice which contains water, mucin, rennin, pepsin, inorganic salts and from 0.2 to 0.5% hydrochloric acid. The flow of gastric juice is initiated in two ways, (*a*) reflexly and (*b*) by a hormone, *i.e.*, a chemical messenger. (See below.) The chemical control of secretion of gastric juice is as follows. Meat extractives, such as are found in soups and beef sauces, when present in the stomach excite secretion and are called secretogogues. It is supposed that secretogogues cause cells lining the pyloric end of the stomach to produce a substance called *gastric secretin* or *gastrin* which is absorbed by the blood and so taken to all the glands of the stomach, causing them to secrete. *Gastrin* is therefore an internal secretion which acts as a specific exciter of other cells. A general name for such a substance is *hormone.*

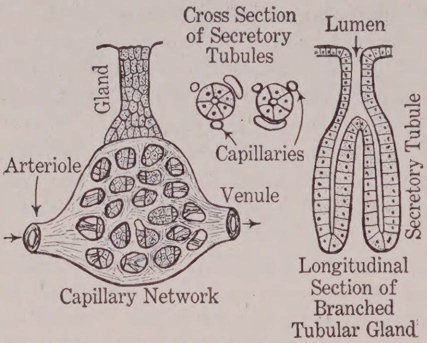
Cross Section of Secretory Tubules
Lumen
Gland
Capillaries
Secretory Tubule
Arteriole
Venule
Capillary Network
Longitudinal Section of Branched Tubular Gland

FIG. 340. — Scheme of simple branched tubular gland. At left, relation to capillaries; at right, section of the gland.

The stomach glands secrete *pepsinogen.* This in the presence of hydrochloric acid becomes *pepsin.* Pepsin causes the hydrolysis of proteins to simpler protein compounds, *proteoses* and *peptones.* Further digestion is completed in the intestine. Rennin coagulates milk. Calcium plays an important part in milk coagulation and in the absence of calcium, coagulation does not occur. Clotted milk is retained in the stomach for some degree of gastric digestion. There is also present in the stomach a weak, fat-splitting enzyme which is capable of acting only on emulsified fats such as are present in milk.

Every now and then the pyloric sphincter muscle, at the junction of the right end of the stomach and the first part of the duodenum, opens and permits the *chyme,* which is the partially digested contents of the stomach, to be discharged from the stomach into the intestine.

Intestine. The first portion of the small intestine is called the *duodenum.* The duct from the pancreas pours pancreatic juice into the duodenum to mix with the food. The duct from the liver, the bile duct, pours bile into the duodenum also. Glands in the walls of the intestine secrete *succus entericus,* intestinal juice. Bile, pancreatic juice and succus entericus bring about the main digestion of food.

Pancreatic juice is similar in appearance to saliva. Carbonates and phosphates make it alkaline. It contains the following enzymes: *trypsin, amylopsin* and *lipase.* Trypsin, a powerful proteolytic enzyme, is not secreted by the pancreas as trypsin, but in an inactive form called trypsinogen. Another catalyst called *enterokinase* is secreted by the intestinal mucosa which activates trypsinogen to trypsin. Trypsin acts on proteins which have been previously acted on by pepsin or on proteins which have escaped the action of pepsin and completes their hydrolysis to amino-acids. Amylopsin acts as ptyalin does. It changes starches to maltose. Maltose is further split by *maltase* to glucose. *Lactase* splits lactose to glucose and *sucrase* changes sucrose to glucose. Maltase, lactase and sucrase are produced by the intestinal mucosa. Lipase hydrolyzes fats into fatty acids and glycerine. The fatty acids form soaps with sodium and potassium ions of the intestinal contents.

Prior to the discovery of gastrin, Bayliss and Starling discovered that the hydrochloric acid of the chyme, discharged from the stomach to the duodenum, coming into contact with the mucosa of the duodenum, causes the production of a hormone, probably of simple organic composition. This hormone, absorbed into the blood stream and circulating throughout the body, is called *secretin.* As it circulates through the pancreas it causes this gland to secrete pancreatic juice and in the liver it promotes the formation of bile. Since the latter is alkaline, it thus indirectly promotes the neutralizing of chyme.

Bile salts are effective emulsifying agents. They aid in the emulsification of the fats and thus promote the action of the fat-splitting enzyme, lipase. Unemulsified fat is apt to form an oily coating over other foods and so the emulsifying action of bile is important in the digestion of protein and carbohydrate substances in food. Digestion of fats practically ceases in jaundice, a condition in which bile is prevented from getting from the liver to the duodenum.

The bile of most herbivorous animals is green while human bile is golden brown in color. Bile pigments are excretions and leave the body with the feces. Cholesterol is also a waste product thrown out by the liver with the bile. Cholesterol has a tendency at times to crystallize in the gall bladder, causing 'gall stones.' Solutions of bile salts dissolve these. The presence of bile in the intestine also stimulates bile secretion in the liver. It is probably the bile salts that are responsible for this. They are probably reabsorbed into the blood and thus conserved, for they do not appear in the feces. They also stimulate peristaltic movements. Constant peristaltic movements of the intestine serve to thoroughly mix food with enzymes and thus promote digestion. Intestinal juice contains enterokinase referred to above. Another proteolytic enzyme, *erepsin*, found in the walls of the intestine, supplements the work of trypsin and pepsin by hydrolyzing certain combinations of amino-acids not attacked by either pepsin or trypsin.

Most of the absorption of food into the blood stream takes place from the small intestine. Water is taken into the blood from all parts of the intestine, but principally from the large intestine. There semi-fluid or solid feces are thus formed. The process of absorption is not yet understood, but a living membrane is necessary.

Proteins are absorbed into the blood as amino-acids. They pass by way of the portal vein to the liver. Blood from the liver is sent toward the heart through the hepatic vein. Monosaccharids are the only carbohydrate compounds taken up by the blood vessels. They are carried by the portal vein to the liver. Fats are absorbed by the intestinal cells into the lymph stream in a hydrolyzed form, are reunited and given to the blood in form of fat. These fats pass into the lacteals and on into the thoracic duct and so on into the heart. The hydrochloric acid of gastric juice and bile in the intestine act as sterilizing agents. The contents of the small intestine are relatively free from Bacteria.

The bacterial flora increases toward the posterior end of the intestine. Bacteria probably produce enzymes which act on proteins, carbohydrates and fats, digesting these to a certain extent. Animals, such as the rabbit, have a large coecum. Cellulose stored there is broken down by the Bacteria present. Bacteria of the large intestine break down proteins into simpler compounds such as skatol, indol, phenol and putrescin. They are formed by putrefaction in the intestine. They are toxic, but are conveyed to the liver, which can usually render them harmless. When there is an excessive production of them, they escape as toxins into the general circulation, producing a condition known as auto-intoxication. *Ptomaines* are highly toxic substances produced by certain Bacteria from food products. These Bacteria are not normal inhabitants of the intestine, but are accidentally introduced with infected food. Bacteria produce gases in the intestine. CO_2 and CH_2 result from fermentation of carbohydrates and H_2S from proteins.

It is probable that, in many cases, Bacteria play no essential part in digestion. Metchnikoff urged the plan to rid the intestine of its usual bacterial flora by the introduction of special harmless lactic acid Bacteria found in certain types of buttermilk. Feces are composed of undigested starches, meat and cellulose and part may be dead or living Bacteria, bile and inorganic salts, such as those of calcium. They should not be regarded as containing the general *cell wastes* of the body. Sooner or later the peristalsis of the intestine causes the accumulation of feces in the posterior end of the intestine (rectum). Its presence there acts as a stimulus for defecation. The relaxation of the anal sphincter muscle is under voluntary control, although this is an acquisition. For some time after birth it is a simple reflex.

Blood and Lymph. Blood is a fluid-circulating tissue. It conveys substances from one part of the body to another. Blood constitutes from 5% to 7% of the body weight of most Mammals. It consists of a liquid plasma in which are the white and red corpuscles. Plasma constitutes about three fifths of the total volume of human blood, while in other Mammals it varies from two thirds to one half of the total volume of blood.

Blood clots or coagulates soon after leaving the blood vessels, either outside the body or among tissues, as in a bruise. This prevents the excessive loss of blood from small wounds. The blood of some persons does not clot readily. This condition is called *hemophilia* and is hereditary. A clot is a jelly-like mass which enmeshes the corpuscles and contracts, squeezing out the clear yellow serum. The clot is composed of a protein network called *fibrin*. Fibrin is produced from a compound called *fibrinogen*, soluble in the circulating blood. The formation of fibrin is the result of a series of cooperating and sequential factors. Calcium salts are necessary, and, in addition, thrombin must be present.

One idea is that fibrinogen + thrombin = fibrin. Inasmuch as thrombin does not exist as such in circulating blood, it must be formed from an inactive agent or precursor, *i.e.*, prothrombin, through the activation of calcium salts. Prothrombin, however, is never found free in circulating blood as it will always be activated by calcium ions (Ca^{++}) and produce a clot. Prothrombin is thought to be combined in a loose form with anti-prothrombin. To disturb the equilibrium of this loose combination so as to liberate the desirable prothrombin, there is brought into play another substance called thromboplastin, *produced when blood vessels are cut.* The *above* theory of Howell may be presented by the following summary, which indicates the series of events in this theory of clotting.

I. Blood Vessels Intact

A. Blood Corpuscles.
B. Plasma.
  (*a*) Prothrombin-antithrombin combination.
  (*b*) Calcium.
  (*c*) Fibrinogen.

II. Blood Vessels Injured

1. Release of thromboplastin.
2. Upsets prothrombin-antithrombin combination and releases prothrombin.
3. Prothrombin, activated by calcium ions, forms thrombin.
4. Thrombin and Fibrinogen forms Fibrin.
5. Fibrin enmeshes corpuscles forming the blood clot.

Sometimes clots form inside blood vessels. This is known as *thrombosis.* If such a clot is carried along in a vessel and lodges in an essential organ such as the heart or brain, it will cause death.

Plasma contains about 80% water; 6% to 8% proteins, such as (*a*) fibrinogen, (*b*) serum albumin, (*c*) serum globulin and (*d*) amino-acids; normally about 0.1% glucose; 0.2% fats; inorganic salts; enzymes; hormones; probably vitamins; gases; immune substances among which are antitoxins and waste products such as urea.

The histology of the cells, erythrocytes and leucocytes, has already been described (p. 370). Corpuscle number is important in diagnosis of some diseases. The important constituent of the erythrocyte is hemoglobin. These cells also contain about 60% water. Hemoglobin functions properly in Vertebrates only when it is confined to the corpuscle.

Hemoglobin with carbon monoxide forms carboxyhemoglobin, a more stable compound than oxyhemoglobin, which is the normal combination, when the corpuscle comes in contact with air. Thus, illuminating gas is a deadly poison since it destroys the oxygen-carrying power of the blood and brings about a rapid cessation of all vital chemical processes in the entire cell population of the body. Nitric oxide is a poison also for a similar reason. In the disease known as chloroanemia, the corpuscles contain little hemoglobin.

After birth, erythrocytes are formed from cells located in the red bone marrow. After severe hemorrhage, there is a rapid production of new red cells although there is a less marked but steady production constantly. The need for this follows from the fact that red cells live only a short time, *i.e.*, from ten to thirty days. It is estimated that 5% to 10% are destroyed daily as they circulate and that special cells in the liver, spleen and elsewhere act on the fragments, conserving the iron and other portions for future use in other new corpuscles and changing the remaining parts into bile pigments.

A description of the white blood cells or leucocytes has already been given. Normal human blood contains about 8000 per cubic millimeter. Certain types increase greatly in certain diseases, others in other diseases; hence a study of the relative numbers of the various types is an important part of the diagnosis of these diseases. Some of the white cells have amoeboid motion and engulf foreign bodies such as Bacteria, rendering them harmless. Such a process is called phagocytosis. Large numbers of certain types of white cells gather wherever there is an infection. They pass easily through the capillary walls into the tissue spaces involved in the inflammation. The phagocytic power varies from time to time, due, it is thought, to a variation in the amount of a hypothetical substance called an *opsonin.* Fat is carried from absorbing cells to lacteals by leucocytes. White blood cells probably have to do with the regeneration of fibrinogen after hemorrhage. They probably aid in the formation of the other plasma proteins. They are thought to have a part in the formation of immune bodies.

Blood is constantly giving and receiving contributions to and from tissue cells. In spite of the constant exchange, its physical condition remains *remarkably constant.* Its reaction is slightly alkaline, the normal variations of the pH being from 7.2 to 7.4. Its osmotic pressure is also quite constant, being equivalent to that of a 0.9% NaCl solution. The inorganic salts are relatively constant in their concentration. The concentration of glucose in health is from 0.1 to 0.12, although it may rise for a short time above this, after a meal. It is well to recall that glucose is the chief energy-producing food, furnishing probably two thirds of all the energy for cell metabolism. There is also a constancy in the percentage of fat and proteins. This equilibrium is very remarkable in view of the in-go and out-go that is taking place. Between blood capillaries and tissue are lymph spaces containing lymph, a fluid something like plasma without red blood cells. Lymph is the middleman between capillaries and cells. The lymph spaces, which are everywhere, communicate with lymph vessels which convey lymph from all parts of the body ultimately to the heart. An abnormal production (collection) of lymph at any part is called *oedema.* Some substance is present in such food as crab meat or strawberries, which has a specific effect in certain individual cases. It is supposed that these foods increase the permeability of capillary walls and so cause local small oedemas to form, known as " hives." These specific substances are *secretogogues.*

The bactericidal power of leucocytes is increased by the injection of dead Bacteria. Preparations of these in physiological saline solutions are *bacterial vaccines.* Inoculation with typhoid vaccine prevents typhoid fever. The presence of special antibodies is an indication of certain diseases. Such a determination is known as *serum diagnosis.* Several types of Bacteria which thrive in the body produce specific poisons or toxins. But the body has a certain power of forming substances called antitoxins or antibodies which neutralize the toxin, and thus develop immunity.

If a rabbit is injected with human serum a few weeks after a previous injection, its blood pressure is lowered, its heart action weakened and breathing is labored. This resulting condition is known as anaphylactic shock. It is supposed that the first injection produces a powerful proteolytic enzyme which rapidly breaks down the protein of the second dose and these broken-down proteins are very toxic.

Spleen. The spleen is a pulpy lymphatic gland. It differs structurally from other glands. For example, blood flows from arterioles into blood spaces, from which it is returned by small veins. In the spleen are reticulo-endothelial cells which are macrophagic, *i.e.*, they engulf foreign particles (except Bacteria) which happen to be present in the blood. The monocytes, a type of white blood cell, have the same property. Some investigators regard monocytes as free reticulo-endothelial cells. The fragments of worn-out red blood cells are engulfed by the reticulo-endothelial cells and monocytes which save the iron and proteins for further use. The remaining portion of the red blood cell is changed to bile pigment and excreted by the liver. Phagocytosis of Bacteria is accomplished chiefly by other types of leucocytes such as the neutrophiles. It has already been stated that in the embryo, red blood cells are made by the spleen and liver and that they are made in the adult from cells in red marrow of bones. However, after severe hemorrhage, the spleen takes up again for a time its old embryonic function. The spleen is not absolutely essential to life, for it has been removed without serious consequences. After removal of the spleen, it seems that yellow marrow of bones takes over the function of iron conservation referred to above.

Circulation of Blood (Figs. 326 and 341). The first correct idea of the circulation of the blood was developed by William Harvey in 1628. The heart contracts and relaxes rhythmically. It contracts completely and all it possibly can each time. The cause of the apparently automatic beat is unknown. According to the *myogenic theory* the rhythmical beat is independent of any nerve impulse although such a cause is claimed by the defenders of the *neurogenic theory.*

A wave of contraction passes over the heart, beginning near the entrance of the large veins. The wave spreads to the auricles, thus causing their contraction; thence to the ventricles, causing *their* contraction and so forcing the blood from auricles to ventricles and from ventricles into the great efferent vessels of the ventricles.

Sometimes the tissue between the auricles and ventricles is diseased and the normal passage of the wave is interfered with.

Potassium salts in the blood favor relaxation of the heart and calcium salts favor contraction. The normal or abnormal heart beat is identified by listening to the sounds of the heart or by the still more modern method of electrocardiography.

Mitral stenosis is a disease of the mitral valve which retards flow of blood from left auricle to left ventricle. When this valve does not close tightly and lets the blood flow back into the auricle, it is known as mitral insufficiency. Similar diseases involve the semilunar valves between the left ventricle and the great aorta.

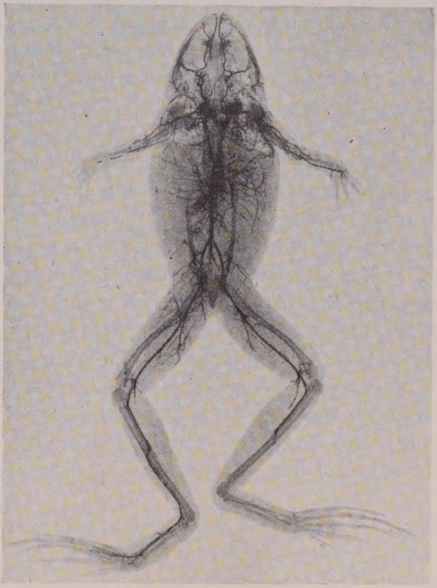

FIG. 341. — X-ray photograph of circulatory system of frog.

At each contraction, from 60 to 90 cc. of blood are forced into the aorta. Contraction lasts about 0.3 second and relaxation 0.5 second. The left ventricle forces blood into the aorta with a pressure sufficient to raise a column of mercury 120 mm. to 160 mm. During the time that the semilunar valves are closed, the elastic recoil of the distended arteries serves to maintain the flow of blood. It will readily be understood that a certain quite definite degree of blood pressure must prevail to keep the tissues supplied with blood. However, if the walls of the arteries become hardened or calcified, as is often the case in old age, there results great fluctuations in arterial pressure. One result may be the bursting of a blood vessel in the brain. The clot of blood formed there puts certain nerves out of commission and causes paralysis, if not immediate death. The normal human heart beats about 72 times per minute, that of the elephant 25 times, that of a frightened mouse is said to be 600 times. The blood makes a complete circuit in from 25 to 30 beats of the heart.

Efferent impulses come to the heart over the fibers of the sympathetic nerves and over the *vagus* (tenth cranial nerve). Impulses over the sympathetic fibers cause an acceleration of the heart beat, while those over the vagus cause a slowing down or inhibition of the heart. Thus the heart can respond to any demand made upon it and adapt itself to varying conditions. External stimuli or emotions may change its action. The size of blood vessels and therefore their blood-carrying capacity, varies with vaso-constrictor and vaso-dilator impulses. These impulses are influenced by afferent impulses from brain or body surface to the *vasomotor center* of the brain. Blood pressure may fall, so that the brain does not contain enough blood to function. The person is pale, dizzy and may faint. If the legs and body are raised and the head lowered, the brain is supplied with blood and consciousness returns. Hemorrhage, or loss of blood, causes low blood pressure. Adrenalin, the hormone secreted by the adrenal glands, causes constriction of blood vessels and therefore aids in maintaining blood pressure. It is used in some operations to decrease bleeding.

Respiration. In Mammals, the increase in size of the thorax at every inspiration lowers the air pressure in the lungs, so that air flows in through the air passages such as the trachea, bronchi and smaller bronchioles to the air sacs. These are minute sac-like cavities whose walls are very thin and composed of elastic tissues lined on the inside with a layer of flat epithelium. In the wall is a rich capillary network. In expiration, the decreased volume of the thorax increases the pressure in the lungs so that some of the contained air is forced out over the same route as it entered. The air does not actually flow from the outside directly into the alveoli at each inspiration, for the air in the alveoli is quite stationary. The rapid in-go and out-go has to do chiefly with the larger passageways. The movement of oxygen and carbon dioxide for the remaining distance is a matter of diffusion.

In a quadruped, the contraction of the diaphragm increases the anterior-posterior diameter of the thorax while the contractions of the muscles of the ribs increases the thoracic cavity in other directions. Expiration is ordinarily a passive act. The diaphragm muscle and tissue relaxes, — this is true also of the muscles of inspiration of the ribs, — while rib muscles of expiration contract. The smooth muscle and elastic tissues of the lungs contract and so the air is squeezed out. In man, there are usually from 14 to 18 respirations per minute. The respiratory epithelium of the human lungs has an *estimated* surface area of about 1000 square feet, 60 times the area of the body surface. The respiratory surface of an Amoeba, a Hydra or a worm is limited to the body surface area.

A chemical analysis of in-going and out-going air reveals that important changes have taken place. This is shown in the following table:

	Nitrogen	Oxygen	Carbon Dioxide
Inspired air	79	20.96	0.04
Expired air	79^+	16	4.38

There is a little change in the nitrogen. A loss in oxygen has taken place, and carbon dioxide is given to the air leaving the lungs.

The following table shows the volumes of gases found in body blood before entering the lungs and also in aerated blood leaving the lungs:

	O_2	CO_2	N
100 volumes venous blood contains . . .	10–12 vol.	45–50	1–2
100 volumes arterial blood contains . . .	20	40	1–2

The arterial blood which is to be distributed to the tissues contains more oxygen and less carbon dioxide. How does this take place? The partial pressure of oxygen in the alveoli is equivalent to a pressure of about 100 mm. of mercury. In the walls are capillaries containing blood. The hemoglobin of the blood entering the lung capillary contains about half as much oxygen as that of arterial blood, *i.e.*, it is not all saturated. Such hemoglobin, when exposed to air at the pressure above named, easily becomes saturated. The cells forming the wall of the alveoli, the cells forming the capillary wall and the surface membrane of the red cells are all permeable to oxygen so that because of its greater partial pressure in the alveolus it is forced through all these into the corpuscle. The hemoglobin which is only half saturated combines with oxygen. The physical aspects of the process are apparent. In the hemoglobin of the corpuscle there is an affinity between hemoglobin and oxygen, forming oxyhemoglobin. When the blood reaches the tissues, the cells may have a lack of oxygen, for they have lowered the supply in the lymph. This causes a lower oxygen pressure in the plasma, and so the oxyhemoglobin breaks down, giving oxygen to the plasma and thence for the same reasons from plasma to lymph, from lymph to cells. Oxyhemoglobin is ordinarily never completely reduced owing to rapidity of the circulation.

Starting with a partial oxygen pressure of 100 mm. of mercury in the alveoli of the lungs, there is a considerable decrease in the cell.

The movement of CO_2 is just the reverse. It passes from cell to lymph to plasma. In the lung it passes from the blood of the capillary into the alveolus. In venous blood it has a pressure of about 5 % of an atmosphere, in the outside air it is far less than this. The CO_2 is carried in the blood in the form of sodium bicarbonate.

The problem of exchange of gases between the atmosphere and the blood and tissue cells is therefore solved by physical and chemical means. The physical laws governing gases are in operation here. Gases exert pressures. In a mixture of gases each gas acts as if it alone were present. This is borne out by the behavior of oxygen and carbon dioxide. The amount of gas that will go into solution depends on the temperature of the solvent, the pressure of the gas on it and the degree of solubility of that gas in that solvent. But solubility alone is insufficient. For it has been found that blood takes up forty times the amount of oxygen that would be absorbed by water. This great discrepancy is due to the great combining power of hemoglobin with oxygen.

The energy used in vital functions is produced by processes of oxidation in cells. The oxygen of the air combines with hydrogen and carbon of foods and forms water and carbon dioxide, thus releasing the energy stored up in the foods. The actual mechanism is not understood. These combinations take place at lower temperatures than when oxidation of alcohol, gasoline, wood or coal take place outside the body. This organic oxidation at such comparatively low temperatures is made possible by the presence of intracellular enzymes or catalysts called oxidases. Oxidative processes are governed by the needs of the tissues and not by the supply of oxygen and food available.

The problem of oxygen supply and carbon dioxide removal becomes vital. The evolution of respiratory devices alone do not solve the question. The evolution of blood and circulatory systems are just as necessary. The study of such forms as the earthworm shows that blood and blood systems are evolved before specialized respiratory systems. The peculiar highly specialized respiratory mechanism of insects carries with it a simplified blood system. The regular sequence of inspirations and expirations in mammals is due to nerve impulses arising in a clump of nerve cells in the medulla, the so-called *respiratory center*. Destruction of this causes cessation of breathing and death. Cells are deprived of oxygen, hence oxidations cease, and this involves the heart and brain.

Normal respirations may be modified by various external stimuli, causing nerve impulses to the muscles of respiration to depart from their normal activities. Respiratory rates may be increased or decreased. Respirations may become deeper or more shallow.

A chemical control of respiration is present also. While the nervous system plays a necessary rôle in control of respiratory movements, it has been found that the hydrogen ion concentration of the blood is also of great importance. Apparently the nerve centers of respiration are very sensitive to this, so that a slight increase of hydrogen-ion will initiate a respiratory movement. On the other hand, a *marked* lowering of the hydrogen-ion will cause apnea. Since the hydrogen-ion is proportional to the amount of CO_2 present, it often appears as though the respiratory movements were controlled by the amount of this gas present.

The movement of air in the smallest bronchioles and alveoli is probably molecular and not molar. The exchange of gases between the air in the alveoli and the air in the ducts where the air is in motion takes place because of the differences in gas pressure and temperature.

In high altitudes the oxygen tension of atmospheric air is very much reduced. At 16,000 feet it is only about half what it is at sea level, to which, in a general sense, the animal respiratory mechanism is adapted. To supply the necessary oxygen, more rapid and deeper respiratory movements are required. But these cause a diminution of the carbon dioxide of the blood. The respiratory center does not get the necessary stimulus and the whole body suffers. The heart is weak, and symptoms such as headache, nausea and dizziness show that the brain and nervous system are affected. This is called Mountain Sickness. But a physiological adjustment takes place. The blood system permits the body to function in this rarefied atmosphere. The red blood cells, the carrier of O_2, increase in number, so that the red cell count is quite often found to be between 7,000,000 and 8,000,000 per cu. mm. The process has been carefully studied by Barcroft, who states that it takes from 2 to 4 weeks to cause the proliferation of erythrocytes.

Temperature of the Body. This is only slightly above that of the surrounding air in the case of most animals. As this changes, the temperature of their body changes accordingly. Such animals are termed ‘cold blooded.’ This is not a good term, for it does not necessarily describe what is referred to. Changeable temperature is a better name. Invertebrates, Fishes, Amphibia and Reptilia belong to this group. On the other hand, Birds and Mammals are constant-temperatured. In spite of variations in the temperature of the surrounding medium, their body temperature is constant. They are said to be *homoiothermic*, while the so-called cold-blood forms are *poikilothermic*. The latter forms do not possess any temperature-regulating apparatus, or, at best, a very primitive one. In cold weather bodily processes slow down in such animals. If the temperature is lowered far enough, life may cease. Fishes have been frozen and later, after slowly thawing out, have resumed active life. In contrast to these, freezing would doubtless kill Birds and Mammals. And yet the latter maintain the same constant temperature of the body in very cold weather as in warm weather.

It is said that Echidna, a Monotreme, and one of the lowest of Mammals is not altogether homoiothermic. When the air is changed from 5° C. to 35° C., the temperature of its body changes 10° C. In cold weather it hibernates and its body then is only 0.5° C. above that of the surrounding medium. Higher animals (such as the hedgehog) that hibernate have a lower body temperature during their winter sleep. The average temperature of human beings (just under the skin) is 37° C., but it ranges daily 0.5° C. above and below this. Fever is a high temperature due to the breaking down of the heat-regulating mechanism which functions as follows: the dilatation of the blood vessels of the skin (nervous mechanism) brings more blood to the surface, where some of the body heat is dissipated. The sweat glands also secrete a watery and warm fluid. The air leaving the lungs in expirations is warmer than that entering. The air contains a certain amount of warm moisture. Evaporation of sweat from the surface of the body tends to reduce the temperature. In humid weather this is interfered with and thus the heat is retained. If the superficial blood vessels are contracted, less blood is at the surface and so less heat is dissipated. Temperature regulation is under control of a nerve center, as is indicated by the fact that destruction of the vasomotor center in the medulla upsets normal body temperature relations.

Metabolism of Foods. Proteins, carbohydrates, fats, oxygen, water and inorganic salts are used in various ways by cells and reappear as waste products which are expelled from the body. One can obtain information as to what takes place with regard to foodstuffs in the body. To do this, the balance sheet of the intake and outgo of carbon and nitrogen; the ratio between the amount of oxygen consumed and the carbonic acid (H_2CO_3) excreted and the energy produced are ascertained.

The chief process concerned in the chemical changes involved is one of oxidation. Lavoisier thought that oxidations in animals were similar to those in the burning of fuel. The two are in many ways alike. But oxidations in organisms occur at low temperatures. This is made possible by the presence of catalysts called oxidases.[1]

In the process of oxidation in the body the energy of food fuels is released. Some of this is used in the other chemical changes taking place, some appears in movements, some as heat. Energy exchange in an animal can be determined. The physical unit of energy used in metabolism studies is the large calorie (C.), *i.e.*, the amount of heat required to raise the temperature of one kilogram of water one centigrade degree of temperature. The energy value of a substance is learned by burning it in a specially made steel bomb in an atmosphere of pure oxygen. The bomb is immersed in a known volume of water. The temperature of the water is obtained before and after the experiment, and the calorific value of the substance is determined by multiplying the increase in temperature of the water by its volume in liters.

By the use of this method it has been determined that oxidation of one gram of protein releases about 5 C. of heat; one gram of carbohydrate about 4 C. and one gram of fat about 9.3 C. Carbohydrate and fat are completely oxidized in the body and give off the same amount of energy there as in a calorimeter. On the other hand, protein is not completely oxidized in the body. The wastes of protein metabolism are compounds which still possess a certain amount of heat energy. This can be determined and must be subtracted from the total physical heat value of proteins, to obtain the physiological value of protein foods.

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[1] An interesting and unusual example of these is luciferase. Luciferase has been obtained in pure form from certain dried luminescent animals. This catalyst attends the oxidation of a compound known as luciferin. During the reaction light is given off but practically no heat.

The energy released in animal metabolism is determined by means of an *animal calorimeter*. Calorimeters are now in use for studying energy production of animals, and also of human beings under all sorts of conditions of health and disease. The general principle is the same as that involved in the use of a bomb calorimeter. They are constructed to measure energy production to the same degree of accuracy. In one experiment performed by Benedict it was estimated that during the time involved, the human subject investigated had consumed 5459 calories, and the amount actually measured by the calorimeter was 5435 calories, which, from the point of view of the scientist, is close agreement. The subject of the experiment was busy at work pedaling a stationary bicycle in the calorimeter. The work performed was recorded and converted into calories and these were added to his other energy output.

Another type of experiment is to determine the basal metabolism of the body as a whole, *i.e.*, the least amount of heat energy produced by physiological processes in a healthy person when the subject is resting quietly in bed. This was found to be 1680 calories in the case of a person of average weight.

Food taken in stimulates heat production.

A considerable amount of the energy of food is also used in muscular work. The atmosphere is colder than the body and so the body is constantly losing heat to the atmosphere. This must be made good by the intake of food. Small animals give off more heat per unit of weight than large animals because they have a relatively greater surface area. Energy is *also* needed by immature animals for growth in addition to the basic energy requirements for fundamental physiological needs; and to the specific production of heat caused by the intake of food; and to the energy needed to maintain the temperature of the body. They actually need more food than adults and so famine affects children more seriously. Inorganic substances of the food furnish no energy.

Proteins are absolutely necessary foods since protein compounds are essential components of cells. When broken down, they appear as waste substances of excretion, as urea and ammonia, which constitute part of urine. The primary use of proteins is to rebuild protoplasm. It has been found that only about 100 grams of protein are needed in the daily diet of the average person. Excess proteins ingested, *i.e.*, amino-acids, are deaminized, the nitrogen usually being eliminated as urea. The remainder is either oxidized in a manner similar to that of carbohydrates or is converted into carbohydrate. The animal body cannot store up proteins. Proteins tend to speed up metabolism and excess energy produced is lost in heat. In diets low in protein, the body protein is saved to a certain extent if carbohydrate food is included in the diet.

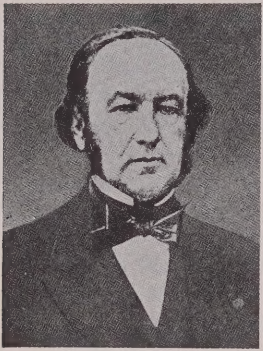
Fig. 342. — Claude Bernard. Pioneer in experimental physiology; created new conceptions of nutrition and metabolism; said to be greatest physiologist of his time. He described the liver as "un véritable laboratoire vital." Courtesy H. Holt and Co.

Carbohydrates are the best source of energy. They are cheaper than proteins; also they are completely oxidized into carbon dioxide and water. These wastes are given off by the lungs and by the kidneys. They are thought to be not as harmful as the excess wastes involved by an unnecessary intake of protein.

In the metabolism of carbohydrates, digestion changes them to monosaccharids, which pass via the portal vein to the liver (Fig. 342). This converts them to animal starch or glycogen, which is stored in the liver up to a certain amount. If an excess of carbohydrate is taken, *sugar* may appear in the urine shortly after meals. This may be considered a defense mechanism. It is an important physiological fact that there is a normal level of glucose (sugar) in the blood amounting to about 0.1 %. The muscles take up glucose from the blood for fuel. Some of it is changed into fat, which is deposited in various tissues. The control of glycogen formation and its release is of the utmost importance. It has been found that a certain hormone produced by the pancreas is concerned in this process. If carbohydrate cannot be converted into glycogen, the animal cannot use it all. And, moreover, if carbohydrate metabolism cannot go on, it has been found that this affects fat metabolism also and, in time, protein metabolism. The result is that no food is of any use, and death takes place, not, however, from the same causes as in ordinary starvation, but rather from poisoning due to an unsuccessful attempt to burn other substances such as fats with the excess production of free acids. Fats are oxidized with much more difficulty than carbohydrates. They oxidize more readily when carbohydrates are being burned. There is a tendency to convert excess carbohydrates into fat.

When glycogen is plentiful in the liver, it is this which is first consumed in muscular work. If there is none of this on hand but plenty of fat, then this is burned. A fat man can live for a number of days chiefly on the fat stored in his body. If a person is starving, the glycogen first disappears, then the fat, and last of all, the protein. Death occurs before the heart muscle or the nervous system is attacked.

Muscular work involves the metabolism of carbohydrate or of carbohydrate and fat. If there are no carbohydrates, then proteins are broken down, yielding over 50% of their weight as carbohydrates. But if carbohydrate and fat are present in the food, then there is no general increase in protein destruction during hard work.

It has been found that a man who does not perform much physical work needs about 2600 calories of food per day, and a working man about 3000 calories. There should be about as much fat as protein and more than twice as much carbohydrate. For example, one analysis of the diet of the professional class indicated 100 grams protein, 100 grams fat, 240 grams carbohydrate, with a total fuel value of 2324° C. Tables showing the protein, carbohydrate, fat and calorific values of our common foods are now available, and from these can be prepared varied menus of proper food values.

Vitamins. However, it is possible to conceive of a diet, prepared from such food tables, that would appear to be perfect in so far as the proper proportions of proteins, carbohydrates, fats and inorganic salts are concerned, but on which animals would starve, or fail to grow, or would develop certain diseases. It is now known that the food must contain at least small quantities of certain obscure compounds which are called vitamins. This name was given by Funk, in 1911, to one of these substances because he thought that it was chemically similar to the amine bodies and that this unknown substance was necessary for life. The words *accessory food substances* have been suggested, but the word *vitamin* is generally used. The function of these is indicated in experiments conducted on animals fed on a diet which lacks individual vitamins.

Vitamin A. This is sometimes called *fat-soluble A.* When it is absent, the animal does not grow and the glands of the eyelid do not function. This leads to inflammation and infection of the eyes and possibly complete blindness. The oil glands in the skin do not function and the fur becomes rough. There is loss of appetite and so loss of weight and lassitude. There is also a high percentage of pneumonia and lung diseases. If the diet continues to lack vitamin A, death eventually occurs. It has been found in nutrition experiments that this vitamin accompanies certain fats. Cod-liver oil is very rich in it. It is also in butter, cream, whole milk and in the yolk of eggs. It is plentiful in the green leaves used as food, such as spinach, clover and alfalfa. It is not plentiful in meats, and plant oils do not contain it. It is present in vegetables that contain the yellow pigment carotin, *i.e.*, in carrots and sweet potatoes. Only small amounts are necessary. Addition of small amounts of butter, cod-liver oil or spinach to the diet corrects the conditions caused by the lack of it. It is not a nitrogenous compound.

Vitamin B, also called *water-soluble B*, was the first to be discovered. When it is absent, there follows failure of growth, lack of appetite, indigestion, anemia and emaciation. A more serious condition is general inflammation of the nerves, leading to paralysis and death. Such a condition has long been known and has received the name *Beri-Beri.* It has occurred for ages in countries where rice is polished, *i.e.*, the outer hulls are removed to make a better appearing and finer food. Eijkmann, in 1897, found after producing beri-beri in chickens by feeding them on polished rice, that he could cure them by feeding them whole rice or the outer hulls. This was also the experience of Funk, in 1911, in experiments on pigeons, and of Susuki in Japan at about the same time. The results are startling. Birds almost entirely paralyzed completely recover in from three to six hours. Vitamin B is not stored in the body, as is true to a certain extent of vitamin A, but must be more or less constantly present in the diet. Animal foods do not contain much of it, but apparently enough for carnivorous animals. It is more evident in plant foods, especially in yeast and wheat germs. It is also present in nuts and fruits, in the green leaves of spinach, and in the common fleshy roots of carrots and beets, and in potatoes.

Vitamin C, or *water-soluble C*, is the anti-scurvy or anti-scorbutic vitamin. Lack of it results in lack of growth. Scurvy eventually appears. Some of the conditions accompanying scurvy are bleeding under the skin or from internal organs, bleeding of the gums, and soreness of the joints with accompanying great pain. The ends of bones become brittle and are easily broken. The heart is also seriously affected. It is said that of all animals studied, the guinea-pig is most susceptible to it and that next to the guinea-pig is man.

Fresh fruits and vegetables contain vitamin C. It is richest in the juices of such fruits as oranges and lemons, and in uncooked tomatoes and cabbages. Meats are not very rich in it. Cows feeding on green grass produce milk that has anti-scorbutic power, but milk from cows that are fed on hay during the winter lacks this substance. Vitamin C is destroyed by heating or storage. Children fed only on pasteurized milk develop scurvy. Orange juice or even the juice of canned tomatoes prevents it.

Vitamin D. Cod-liver oil cures and prevents rickets, a disease in which the course of metabolism is abnormal. Bones do not receive the proper complement of lime salts. Lime and phosphoric acid are needed to make proper bone tissue. But vitamin D is also necessary. At first it was thought that vitamin A substances were sufficient. Butter, however, contains vitamin A but does not prevent rickets. Cod-liver oil contains not only vitamin A but also vitamin D, the anti-rachitic specific. Certain treatment destroys the vitamin A property of the oil but not the vitamin D. During recent years there have been many evidences that rickets could be cured by exposing the body to radiations of ultra-violet light. Recently both Hess and Steenbock have demonstrated that oils or fats that had no vitamin D properties would take on such properties if they were exposed to ultra-violet radiations. And so, fats, circulating in the blood just under the skin, if exposed to ultra-violet radiations, take on the vitamin D or anti-rachitic properties.

Vitamin E. This promotes fertility. If it is lacking in foods otherwise adequate, sterility results. It is present in such foods as lettuce, wheat embryos, meat, rolled oats, in large amounts of milk fat, in yellow corn.

Inorganic Substances. Certain inorganic substances in food are also necessary. Iron, so necessary for hemoglobin, is best furnished by green vegetables in the diet. It is also found in red meats, eggs and milk. Phosphorus is also necessary to provide for growth of the bones; it is present in sufficient quantities in milk, meats, egg yolk, beans, peas and nuts. Calcium is also needed for bone formation and other purposes. For mankind the principal source of calcium is in milk. "Hard" drinking water also contains calcium in a form that can be used by the body.

A small amount of iodine is necessary. Some investigators believe that water and food supplies in certain regions do not furnish the adequate iodine supply resulting in abnormal conditions associated with the thyroid gland.

Excretion. Excretion begins in the various cells of the body. Wastes of cell activity are discharged from them and find their way eventually into the blood. The amino-acids of proteins are taken up from the blood by the cells. In the process of metabolism the broken-down proteins and amino-acids appear as ammonia. This is toxic. It is rendered harmless by the ever-present carbonic acid of the blood with which it forms ammonia carbonate, This is carried to the liver and there the ammonia carbonate loses two molecules of water, forming urea $(NH_2)_2CO$. The ammonia is thought also to neutralize other harmful acids, such as lactic acid, that develop during muscular exercise. The urea is discharged from the liver along with other nitrogenous wastes into the blood stream.

Fat circulating in the blood may be used as fuel. Fat stored in adipose tissues is later taken up by the blood also. Before being burned it is probably changed to fatty acid and glycerine. By a series of physiological oxidations they are eventually changed to carbon dioxide and water. Oxidation of carbohydrate (glycogen or glucose) also occurs by a series of steps resulting in the formation of carbon dioxide and water.

The blood is the vehicle by which waste products such as CO_2, H_2O, urea, etc., are carried to the organs of excretion. Here waste products are constantly being removed, although it must be remembered that the blood constantly contains waste products. Gases leave the body via the lungs or gills. Water is excreted from the lungs. The sweat glands, used primarily as part of the heat-regulating system, also give off water, nitrogenous wastes, inorganic salts and gas. The liver excretes bile pigments and cholesterol into the intestine. It is known that the cells of the intestinal wall excrete inorganic substances present in excess, such as calcium or magnesium. The salivary glands, tear glands and mammary glands may also secrete traces of waste substances.

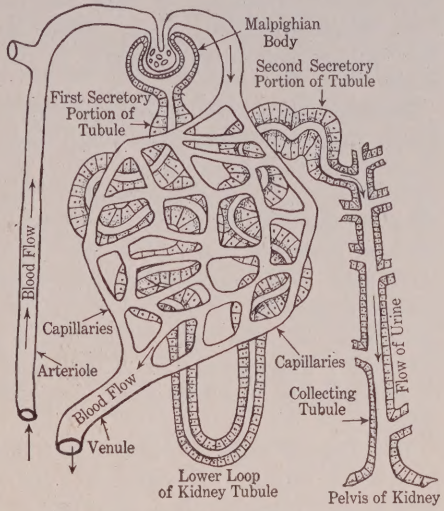
Malpighian Body
Second Secretory Portion of Tubule
First Secretory Portion of Tubule
Blood Flow
Capillaries
Arteriole
Blood Flow
Venule
Capillaries
Collecting Tubule
Flow of Urine
Lower Loop of Kidney Tubule
Pelvis of Kidney

Fig. 343. — Plan of a nephridial (urinary) tubule and its blood supply.

The kidney, however, is the chief organ of excretion of wastes of protein metabolism. The vertebrate kidney is a mass of tubular glands all joining to discharge the liquid waste products by a few main ducts into a space from which the wastes pass into a ureter and from this to the outside. These tubular glands radiate out toward the periphery, not as simple straight tubes but each unit or urinary tubule is coiled (Fig. 343). The outer terminus is enlarged and is called a *Malpighian body*. This consists of a sac containing a network of capillaries. Portions of the nephridial tubule adjacent to the Malpighian body are composed of larger cells. This part of the gland is invested with an especially rich capillary network. It is the function of these glands to remove waste substances from the blood. This may be done in part by the physico-chemical processes of filtration, and osmosis, but careful experiments show that selective secretion of the cells is concerned.

During excessive secretion of urine, an increase in oxygen consumption of kidney cells takes place, indicating activity of the kidney cells. Urea and glucose in the blood act similarly in a physico-chemical way, but urea is excreted and glucose is retained.

Urine is an aqueous solution of waste compounds, a little heavier than water and slightly acid in Man and Carnivora but alkaline in Herbivora. Eighty-five per cent of its organic wastes is in the form of urea. It contains other organic wastes such as uric acid and inorganic salts — chlorides, sulphates and phosphates of sodium, potassium, calcium and magnesium. When Wöhler made urea synthetically, in 1828, the barrier separating organic from inorganic chemistry was broken down. It indicated that the same chemical laws operate in the living and non-living world.

Ductless Glands and Hormones (Fig. 339). There are certain glands present in Vertebrates which secrete chemical compounds directly into the blood stream. These glands have no ducts and are therefore called ductless glands, or *endocrine organs.* Some of them are visible to the naked eye while others are seen only under the high powers of the microscope. It is entirely possible that there exist some endocrine organs concerning which nothing is known at present. Their secretions contain vitally important substances called *hormones*, which control or regulate physiological processes. This means that in addition to the nervous control of physiological processes there is present a system of *chemical control.*

The Thyroid gland is located just below the larynx and in front of the trachea. It consists of a right and left lobe connected by a middle isthmus. It is composed of very small more or less spherical sacs whose walls consist of a single layer of short columnar epithelium. In the cavities of these sacs is a colloid substance. Located in the substance of each lobe are two small parathyroid glands. Both these glandular structures are richly supplied with blood vessels.

Sometimes the thyroid does not develop in children. Such individuals are known as *cretins.* They fail to grow physically or mentally. The growth of the brain is interfered with. Although these persons may live for a number of years, yet they remain idiotic and infantile. If this condition is discovered early enough, the administration of thyroid extract from the gland of the sheep, for example, will entirely change the individual from abnormal to normal. The hormone necessary for growth and normal development, lacking in the cretin, is supplied by the thyroid extract. It is known that iodine is concerned in this substance, and a compound called *thyroxin*, obtained from thyroid glands of animals, possesses it. The formula of thyroxin is $C_{15}H_{11}O_4NI_4$.

Sometimes the thyroid atrophies in adults and causes marked abnormalities. This is known as *myxoedema.* The hands, feet, face and lips become enlarged, the skin dry, the rate of metabolism decreased and deranged. The general intelligence is lowered. Administration of thyroid extract corrects these abnormalities due to the absence of the hormone. In some cases where the body cannot get a supply of the iodine compound from which to manufacture the hormone, an excessive development of the gland takes place. The vesicles coalesce and fill with useless colloid secretion. The gland eventually becomes an enormous cyst or tumor which can be removed surgically. This is known as *chronic goiter.* It has been found to be especially frequent in certain lake and river districts. Attempts have been made to correlate it with the absence of iodine in the food and water of these localities. *Exophthalmic goiter* is a more serious type. In this case, an excess of the secretion is produced. Metabolism is speeded up, the heart beats faster, there is loss of muscular power and development of bodily weakness, the person is very nervous and the eyeballs protrude. This is often fatal. When the entire thyroid is removed, death ensues. This is probably due to the removal of the parathyroids which are embedded in the thyroid substance. When the parathyroids are removed from a dog, convulsive contractions of the muscles follow. The animal has no muscular control. Death occurs in about ten days. Certain very toxic substances appear in the urine. There is also an unusual elimination of calcium. A certain type of convulsions in very young children is thought to be due to a deficiency of parathyroid secretion. The feeding of calcium salts results in a disappearance of the symptoms. Deficiency in parathyroid secretion results in changing the reaction of the blood to a more acid condition, and decreased metabolism of protein. In the removal of chronic (colloid) goiter, surgeons are careful not to remove the parathyroids.

Thymus. The thymus is not found in Invertebrates but occurs in all Vertebrates. It is functional in man at birth and is active in early life. Certain evidence indicates that it is a gland of internal secretion. It grows for the first two years of life, then degenerates, and this is usually complete at puberty. If it persists longer, the period of childhood is prolonged. Its secretions appear to retard the attainment of the mature condition. It seems to check the action of other glands having to do with normal development.

Pituitary Gland. It is located in the under side of the front part of the brain. It has three parts and it is probable that each part has distinct functions. Removal of the pituitary produces profound disturbances, but not necessarily death. When it is removed in young dogs, they fail to grow and remain sexually and mentally undeveloped. These effects are supposed to be due to the removal of the anterior lobe. Removal of the posterior lobe results in the production of a great amount of urine. This is similar to a disease called *diabetes insipidus*, which is supposed to be due to an affected posterior lobe of the pituitary. Some dwarfs have very small pituitary glands. In human beings with deficient anterior lobe secretions, the individual shows conditions similar to those in which this gland was removed in young dogs. Some giants have unusually large pituitary glands. Sometimes this gland begins a sudden growth in the adult. The bones of the head, hands and feet increase greatly in size, the lower jaw develops to an unusual size and severe headaches accompany these changes which result from an increased secretion of the gland. Some cases are benefited by surgical removal of the pituitary tumor. Administration of pituitrin, obtained from the pituitary glands of animals, helps to correct abnormal conditions produced by the lack of pituitary hormone.

Pancreas. Located among the ordinary glandular cells of the pancreas are small clumps of cells known as the *Islands of Langerhans.* It is now known that these cells secrete into the blood a hormone called *insulin.* This is necessary for the normal metabolism of sugar in the body. When sugar is not metabolized, it produces a disease known as *diabetes mellitus,* which appears to be caused by a failure of the islands of Langerhans to produce insulin or pancreatic hormone. In diabetes, the sugar absorbed from the intestine is carried to the liver by the blood. But in the liver, this sugar cannot be changed to glycogen nor stored, due to the absence of the hormone. Neither can sugar be oxidized. It is thrown back into the blood stream. As a consequence, metabolism of fats and proteins is interfered with and, due to the general derangement of metabolism, death results from *ketosis.* This is a condition in which bases are decreased, due to the excessive formation of acids in the body. Powerful neutralizing devices are present in health to prevent this, namely, the buffer substances.

Adrenals. These are a pair of small glands near the kidneys. In man there is one just above each kidney. Their secretions (hormones) are necessary for life. When diseased, the person is physically prostrated and the condition is accompanied by vomiting. The skin becomes bronzed in color. Death follows. This is called *Addison's disease* because it was shown to be connected with a disease of the adrenals by Thomas Addison in London in 1849. When the gland is removed in animals, death occurs in a few days. A hormone from one portion of the gland can be isolated in pure crystalline form. This was done in 1901, and in 1906 it was made synthetically and is sold under trade name of "*Adrenalin.*" A certain quantity of adrenalin in physiological saline solution causes the contraction of arteries. It is used therefore in checking the flow of the blood from wounds and also hastens the formation of a blood clot. There is one part of adrenalin to 500,000,000 to 1,000,000,000 parts of blood.

Adrenalin effects a rise in blood pressure; produces a quickening of the heart; inhibits the contraction of the smooth muscles of the respiratory passages, causing them to relax, and hence affords relief in spasmodic contractions of asthma; it causes a mobilization of sugar from the liver glycogen; hastens clotting of blood and counteracts fatigue at the myoneural junctions. In excitement the adrenals produce more adrenalin. As a result the blood contains more sugar. The muscles have more fuel at hand. And this means that the animal is in better condition to fight or fly as the case may be.

Sex Organs. The processes by which mature eggs are produced from the ovary; by which sperm are produced from the testis; fertilization; development; preparation of uterine tissues for the developing embryo; of intra-uterine feeding, are all physiological and much remains to be discovered regarding them. We are here concerned particularly with the hormones produced by endocrine tissues in the gonads.

The interstitial cells, located between the tubules of the mammalian testis, produce a hormone that has to do with the development of secondary male sex characters; as, for example, the antlers of the male stag; the plumage of the male fowl; and in man, the masculine figure that develops after puberty and his beardedness and deeper masculine voice. There are endocrine tissues in the ovary also and these activate the development of secondary female sex characters. In the castrated cock, the plumage and other male characters change so that the animal takes on the general appearance of a female. A corresponding operation on a female causes a change from female to male plumage. Subtraction of hormones are believed to cause these changes (Fig. 344 *A*). It is said that after castration of male cattle, there is a change in the flavor of the flesh; there is a tendency toward the development of adipose tissue and the temperament is mild.

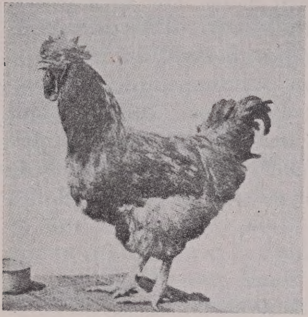

FIG. 344*A*. — Buff Orpington hen with ovarian tumor. It had head furnishings, plumage and spurs of a cock. Its entire behavior was like that of a male bird. (From Crew: 1922.)

The endocrine tissue of the ovary produces a hormone which causes marked changes in the tissues of the uterus, whereby the latter is made ready to receive the egg. The special preparation of the uterus is even more marked if the egg has been fertilized and this further change is activated by ovarian hormone. This hormone production ceases when the young animal is born and the uterus soon thereafter resumes its normal condition (Fig. 344 *B*). An ovarian hormone also stimulates the mammary glands to develop.

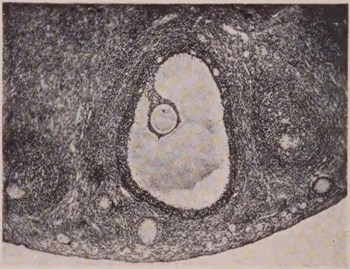

FIG. 344 *B*. — Photomicrograph of part of cat's ovary. The large space indicates a Graafian follicle. At one side is an ovum. The cavity is filled with follicular liquid. At ovulation, this and the egg are discharged and the space is filled with *corpus luteum* tissue. This produces a hormone as described in the text. (Photo by Cooper.)

After a certain period of years the mammalian female ceases to produce eggs. The ovaries diminish in size; the hormones referred to above are no longer formed and the reproductive period is at an end.

8. *Interdependence of the Endocrines.* When the thyroid is removed experimentally,

the anterior lobe of the pituitary increases in size. When a gonad is removed, the cortex of the adrenal grows larger. On these and other grounds, the endocrinologist is convinced of an interdependence among the endocrine glands. To unravel this intricate relationship is one of the problems of modern physiology.

PHYSIOLOGY OF ADJUSTMENT

Function of Irritability — Receptors. Amoeba is irritable to external stimuli. Different parts of its protoplasm do not respond respectively to special stimuli. At the other end of the animal series, however, the Mammal has many special (see page 397) organs of sense, each of which is aroused by certain particular stimuli. As with all organs, a study of the comparative anatomy and physiology of animals shows a gradual evolution of special sense organs. Space does not permit of more than an enumeration of these special sense organs as they occur in higher Mammals.

1. *Light.* The sense organ in the Vertebrate is the eye (Fig. 338). The parts of the eye sensitive to changes in light are the sensory cells of the retina. Different light rays (color) and rays of different intensity produce some change in the protoplasm of the sensory cells of the eye (Fig. 345). These cells are connected with fibers of the optic nerve. Nerve impulses are consequently aroused in these nerve fibers, which impulses pass along into the brain stimulating certain brain cells.

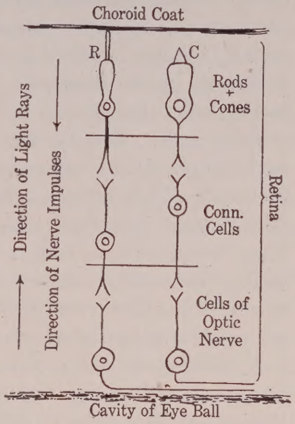

Fig. 345. — Cell arrangment in retina. Compare with Figure 338.

2. *Sound.* The sense organ concerned with this type of stimulus is the ear (Fig. 337 *B*). Sound waves cause the ear drum to vibrate. Vibrations of the ear drum are communicated by the chain of three small bones in the middle ear to the membranous window (*fenestra ovalis*) between the middle ear and the inner ear. On a spiral shelf of the membranous inner ear are thousands of sensory cells (of hearing) immersed in a fluid in the membranous

cochlea. Vibrations of the fenestra ovalis sets up vibrations in this inner fluid (*endolymph*). Certain vibrations stimulate certain sensory cells. The nature of the endolymph vibration depends, as is evident, on the nature of the external sound. Once these sensory cells are stimulated, the momentary change produced in their protoplasm is communicated to the nerve cells with which they are connected and so particular nerve impulses pass over fibers of the eighth nerve, to arouse certain cells in the brain.

3. *Equilibrium.* When the body, or especially the head, changes its position in any way, certain brain cells are aroused and thus the body is aware of the change in position. The external sense organ involved is not only that of the eyes but also the semicircular canals associated with the auditory apparatus. There are three of these membranous canals or tubes in each ear. One is horizontal, two are vertical to this and at right angles to each other, as shown in the diagram. Each semicircular canal possesses an enlargement known as an ampulla and in these ampullae are sensory cells. The canals are filled with endolymph and in this endolymph are fine calcareous particles. Suppose the head falls forward. Then certain cells on one side of this apparatus will be stimulated. Impulses pass at once from these cells over nerve fibers to appropriate cells in the brain. Suppose the head is erected again, then other sensory cells are stimulated. If the head falls to one side, then certain other cells will be stimulated. So the animal is constantly informed of its position.

4. *Odors.* In the mucous membrane of the upper back part of the nasal cavities are sensory cells, which are stimulated by odoriferous particles given off into the air by certain substances. These sensory cells of smell are connected with fibers of the olfactory nerve, and hence impulses are carried to special cells in the brain.

5. *Chemical.* On the tongue (Fig. 337 *A*) and back part of the mouth are located special and various sensory cells which are stimulated by certain components of the food in solution. These taste cells occur in special organs. Impulses aroused in this way in these sensory cells of taste are carried by certain nerve cells to certain other nerve cells in the brain.

6. *Touch.* The contact of external objects with the surface of the body stimulates appropriate sensory organs located in the skin. These impulses aroused pass on to certain nerves and from these to certain nerve cells in the brain. There are over 500,000 such

sense organs distributed over the surface of the body. They are closer together at some places than others and so some portions of the skin are more sensitive than others. The tip of the tongue is most sensitive, while the back of the neck is least sensitive.

7. *Muscles.* When weights are held in the hand, or when parts of the body support a weight or when a movement takes place, then the consequent contraction of muscles involved stimulates end arborizations of certain nerves or sense organs, with the result that appropriate impulses are sent over nerves to cells in the brain. Thus we are not only aware of differences in weight of objects, but what is more useful and usual, we are constantly informed of changes in the muscular system. That is, we are aware of our muscular movements. This muscle sense works with the sense of equilibrium and vision in making locomotion possible.

8. *Pain.* There is evidence that widely distributed over the body are special nerve endings which are aroused by injurious stimuli. The sensations aroused in the brain are those of pain.

9. *Heat and Cold.* Two special groups of end organs distributed like points throughout the surface of the body are stimulated by changes in the temperature of the external medium. The so-called heat spots are stimulated by temperatures higher than that of the skin, while the cold spots are stimulated by temperatures lower than that of the skin.

10. *Hunger.* This is an ill-defined sensation aroused by lack of food. It is natural to associate it with the stomach. It is now known that, accompanying hunger pains, there occur violent contractions of the wall of the stomach, so that the sense organ of hunger may be regarded as consisting of ends of sensory nerves located in the stomach. These sensations inform the individual that the cells of the body need more food.

11. *Thirst.* When very thirsty, we note a feeling of dryness in the membranes of the throat and pharynx. The sensation informs the individual that the body cells generally need more water for the chemical changes incident to life.

12. There are a great many other kinds of sensations aroused by a variety of stimuli. Although special sense organs and conducting nerves are not known, yet it is believed that some sort of apparatus must be present to carry out these functions. The feeling of fatigue, sexual feelings and the sensation of nausea are examples of these; the vague feelings of well-being or malaise

are other examples. All these structures in which sudden changes in the conditions of the environment produce changes in certain definite portions of their protoplasm are called *receptors*. They are sentinels in the front-line trenches. In some cases special epithelial cells are arranged in special sense organs, in others the end of a nerve has to suffice and this is probably not as sensitive as the first. If we stimulated the sensory cells of the eye with a small object directly, we probably would " see " a flash of light. But it would all be quite useless to us. Each type of receptor is specialized to react best to its own appropriate stimulus, *i.e.*, it is selective. Sound waves beat against the skin, but the skin is not affected by them.

Function of Conduction. Protoplasmic changes produced in receptors are continued along definite conducting organs called *nerves*. The superficial protoplasm of the Amoeba is receptive, but the change in it is carried into the deeper protoplasm, and the Amoeba responds by some sort of contraction. In the study of Hydra, we found indications of the early appearance of special structures for each of these functions of adjustment. There are two muscles of our upper arm concerned in bending movements of the forearm. In front of the upper arm is the biceps muscle. Just opposite it on the other side is the triceps. When we flex the forearm against the upper arm, the biceps contracts and the triceps relaxes. This shows that the bending of a part of the body involves the contraction of certain muscles and relaxation of others. Or, one is a case of excitation while the other is a case of inhibition. Strychnine injected under the skin of a live frog upsets all normal muscular coordination. On the slightest stimulus from without all the skeletal muscles of the frog contract simultaneously and the body and the legs are stretched out in a convulsive rigidity, making locomotion impossible. It is hard to conceive of locomotion in any animal where contraction of one part is not compensated for by relaxation in another. This is true even of the Amoeba. While the protoplasm of one part of the Amoeba's body is contracting it is relaxing at another part.

Nervous System. In the higher animals this coordination is accomplished by the nervous system. The nervous system, we have seen, has evolved from the generalized condition seen in lower animals like the Coelenterates and Flatworms to the highly complicated nervous systems of a Vertebrate and finds its highest expression in man. The nervous system not only is concerned in bringing about proper muscular contractions by which the skeletal levers act so as to move the animal either toward or away from certain stimuli, but it regulates the activity of certain vital internal organs. For example, modifications in the rate of the heart beat and the regular rhythm of respiration are under nervous control. That part of the nervous system that in a sense lies outside of the central system, the so-called sympathetic, has nerves which follow the blood vessels. It forms a network or plexus of nerves about the stomach, heart, intestines and kidneys. It controls involuntary or smooth muscle. We have already shown that certain physiological processes are also under the chemical control of hormones. The central nervous system is somehow changed by repeated stimuli of the same sort. Although we do not know the anatomy involved, yet there is no doubt that memory has some neurological basis. Moreover, the appearance of memory leads to possibility of making generalizations and so rational thought comes into existence. Discussion of such matters is beyond the scope of this volume. It should be kept in mind that reason, and the appreciation of art and even the knowledge of right and wrong, are all in a sense physiological and have a morphological background. It is possible here to present only a brief picture of the anatomy and physiology of the *nervous system.*

The simple apparatus which brings about adjustments in a Hydra soon appears in higher animals as a definite mechanism called a *reflex arc.* This in its simplest form consists of three parts: (*a*) *receptor;* (*b*) *adjustor;* (*c*) *effector.* These are physiological rather than anatomical terms. An anatomical picture gives a clearer explanation of just what is meant by it. Among the cells of the skin is a sensory or afferent nerve cell. This is not only a receptor, but the impulse aroused passes over its axone to a central organ, such as a ganglion in the nerve cord of the earthworm or to the spinal cord of a Vertebrate. In most cases, as shown in the description of the receptor system, special sense cells (of the sense organs) are acted on by the stimulus, and these sense cells are connected with afferent nerves.

The sensory or afferent impulses pass over connecting nerve branches (*synapsis*) into a motor nerve-cell body. It arouses an impulse in this cell and the impulse continues out (efferent) over its axone. This is the adjustor part of the reflex mechanism. The impulse is carried out over the motor cell axone to a muscle (effector), causing a chemical change in the muscle which is expressed by a contraction. Nerve impulses pass over axones in one direction; over sensory nerve axones towards a nerve center; over motor nerve axones outward toward a muscle or gland. The nervous system of Vertebrates is made up of a great many; some relatively simple and *many complicated reflex arcs.*

The nervous system of a Vertebrate may be thought of as consisting of thousands of pathways or nerve tracks along which sensory impulses, aroused by this or that form of stimulus, pass into the central system to the higher centers in the brain, and also of thousands of tracks of neuraxones over which motor impulses pass from the higher centers out to muscle or gland. The nerve tracks involved may consist of a chain of nerve cells. Another complication consists in the fact that although the activities of lower animals may at times appear to be a mass of reflexes, yet only too often they are not all simple and machine-like as the extreme mechanist would claim.

One afternoon the writer observed a wasp dragging a very much larger black spider over the ground. After proceeding laboriously for about fifty feet the wasp encountered a pile of stones. In the attempt to pass this obstruction the spider was dropped far down between two stones. The wasp flew about, then returned, and in a few moments reappeared dragging its prey successfully to the other side of the barrier. To say that this series of movements is merely a succession of complicated reflexes would be an unsatisfactory explanation. In man, moreover, some incoming impulses are referred to higher centers which somehow block the reflex response. Memory or better judgment, we say, urges delay or caution. The nervous system is composed of many millions of cells, and it is a reward of the long, arduous labors of neurologists that their work has been crowned with the discovery of some idea of order underlying this great complexity.

1. Spinal Cord. In the Vertebrate a slight skin stimulus arouses a receptor in the skin. A nerve impulse passes over the sensory nerve cell to the sensory cell body in the ganglion on the posterior root of a spinal nerve. The impulse continues from this via the posterior root into the posterior horn of gray matter of the spinal cord (Fig. 346). (1) The nerve fiber involved may pass around in the gray matter of the same side and connect with a

motor cell in the anterior horn. In this case, a motor impulse would pass out along its axone in the anterior horn, and out in the same spinal nerve and end in a muscle directly under that portion of the skin stimulated, (2) or the sensory nerve cell spoken of, may also join with an intermediate neurone which extends for some distance up or down the cord in its white matter and has branches

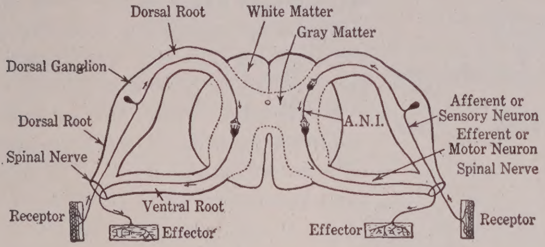
Dorsal Root
White Matter
Gray Matter
Dorsal Ganglion
Dorsal Root
Spinal Nerve
Receptor
Ventral Root
Effector
A.N.I.
Afferent or Sensory Neuron
Efferent or Motor Neuron
Spinal Nerve
Effector
Receptor

Diagram of Cross Section of Spinal Cord
Showing a Pair of Spinal Nerves and the Essential
Parts of a Reflex Arc.

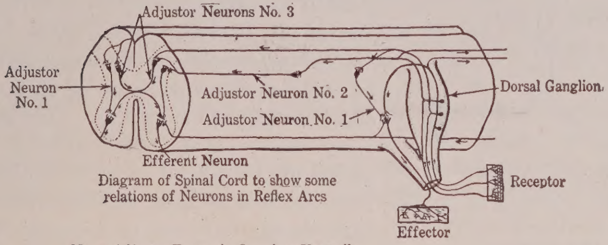
Adjustor Neurons No. 3
Adjustor Neuron No. 1
Adjustor Neuron No. 2
Adjustor Neuron No. 1
Dorsal Ganglion.
Efferent Neuron
Receptor
Effector

Diagram of Spinal Cord to show some
relations of Neurons in Reflex Arcs

No. 1 Adjustor Transmits Impulses Ventrally
No. 2 " " " Longitudinally
No. 3 " " " from One Side of Cord to the Other
(From Curtis and Guthrie)

FIG. 346. — Neuron relations of the reflex mechanism. The brain would be at the right of the lower figure. Arrows indicate direction of flow of nerve impulses. (From Curtus and Guthrie, *Textbook of General Zoology*. Copyright 1927, John Wiley and Sons, Inc. Reprinted by permission.)

which connect with motor nerve cells at several levels of the cord so that motor impulses may go out over several spinal nerves, (3) or motor cells on the other side of the cord may be affected as well; (4) or this sensory nerve cell spoken of may connect with a cell whose axone extends up the cord to the medulla. Here it connects with other neurones which carry the impulse higher up. For example, it may connect with neurones whose axones extend up to the cortex (outer rind of gray matter) of the cerebellum, or it may go up to a center in the brain, and from this to the cortex of the cerebrum (Fig. 347).

The spinal cord, therefore, consists of a segmental series of reflex centers. It is also a highway over which stream two sets of impulses. Over fibers lying in posterior region of the cord (sensory) impulses stream upward toward the brain. Over fibers lying in the anterior region of the cord, motor impulses are streaming down the cord, some passing out over spinal nerves at this level and others at another level.

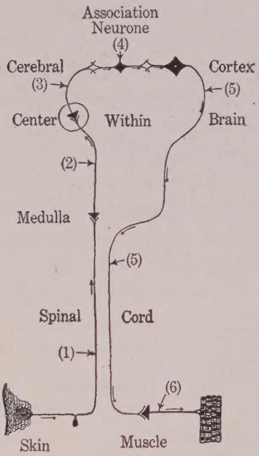

Fig. 347. — Diagram showing chain of neurons over which an impulse may pass from skin to cortex of cerebrum and back to a muscle.

2. Medulla. Some afferent impulses end in the medulla and are there shunted off into motor impulses. The medulla is an automatic center of the most vital sort. It regulates heart action, it controls respiration and the contraction of the arteries and, therefore, has a great deal to do with blood pressure, so important in all physiological activities. It is the control center of such simple reflexes as winking, chewing, swallowing, vomiting, sneezing and coughing. It is also a relay station from which afferent impulses are continued on up to the brain, and from which motor impulses from the higher centers are sent on down the cord.

3. Cerebellum. This is relatively larger in man and apes than in other Vertebrates. Experimental evidence and observations on human beings with a diseased cerebellum indicate that the cerebellum is not an organ of intelligence but governs the coordination of muscular movements, especially those concerned with locomotion. For example, a pigeon from which the cerebellum has been removed cannot fly or walk. It tumbles over. Dogs thus operated on behave similarly. They may recover partially in time, but this is because a coordinating mechanism of a sort is set up in the cerebrum between the eyes and limb muscles. The result is similar if there is injury to the sensory organ of equilibrium, namely, the semicircular canals (Fig. 348).

4. Cerebrum. The brain consists of an outer rind or cortex of gray matter in which are located millions of nerve-cell bodies.

The convolutions and fissures increase the area for location of these cells. From them, axones extend down into the interior, and other axones from centers in the interior pass up to the cortex. *Association neurones* connect one part of one side of the cortex with another portion of the same side. *Commisural neurones* connect one hemisphere of the cerebrum with the other. The brain is not a solid mass, but contains cavities or ventricles which can be traced back to the canal of the embryonic nerve cord. The *optic thalami* are a pair of large internal ganglia or nuclei which receive impulses from neurones extending into them from centers in the medulla. These sensory impulses pass up over other neurones to the cortex. Motor impulses arising in the cortex pass down over certain groups of fibers to motor centers in the interior, and from these over other neurones to centers in the medulla, and from this possibly down the cord to the sciatic nerves and down to the toes.

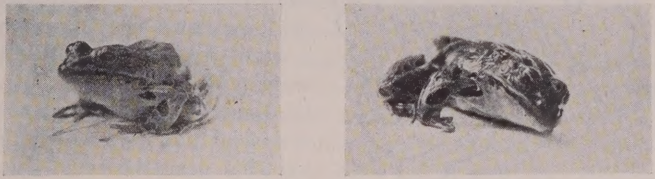

FIG. 348. — Relation of semicircular canals to equilibrium. Frog on the left is normal; in the other frog the equilibrating apparatus of the right ear is not functional. Note that the head is turned to the left. (Courtesy of Dr. Joseph Tulgan.)

A dog from which the cerebrum has been removed (and in one case the animal survived for a year and a half) breathes, walks, runs and swallows, if food is placed in its mouth. It is a mere automatic machine. It has no memory, no fear, no feelings. A similar experiment on a series of Vertebrates from lower to higher indicates the increasing importance of the cerebrum as one goes "higher" in the scale. There are two chief fissures on the outer side of each hemisphere. One of these, the *fissure of Rolando*, begins at about the middle of the upper surface and extends downward and forward. The *fissure of Sylvius* is on the lateral face of the hemisphere and extends from in front toward the rear. The frontal lobe of the brain is above the fissure of Sylvius and anterior to the fissure of Rolando. The *temporal lobe* is below the fissure of Sylvius. The *parietal lobe* is behind the fissure of Rolando.

The *occipital lobe* is most posterior of all, being behind the parietal and temporal lobes.

By various lines of evidence it is known that the cortex has a geography of its own (Fig. 349). In apes and man, the cortex just in front of the fissure of Rolando contains motor neurones which control the movements of the body. There is evidence also of an orderly distribution. Beginning with the upper reach of this region and passing down and toward the fissure of Sylvius occur: (1) neurones which control the movements of the legs; (2) lower down, neurones which control movements of the trunk; (3) cells which control the arms; (4) cells which control facial muscles. (5) On the left side near the cells which control the movements of the hands are probably special cells controlling the writing of words. (6) Near the face and tongue center on the left side are probably cells controlling speaking of words.

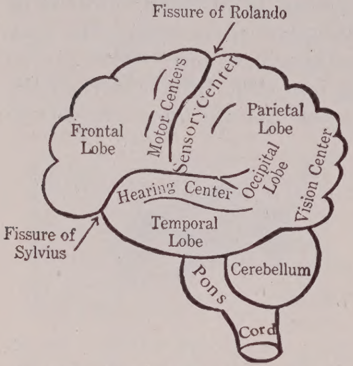

Fig. 349. — Side view of human brain showing sensory and motor centers.

In the back part of the occipital lobe is a region containing cells which control vision. This is called the *visual center*. On the side of the hemisphere just below the back end of the fissure of Sylvius are cells which control hearing. This is the *auditory center*. Associated with both the visual and the auditory centers (on the left side) are probably cells which are associated with reading words and hearing words. In the cortex on the inner face of each hemisphere are the *centers for smell and taste*. Just back of the Rolandic fissure is the cortical center of cutaneous senses.

Observations of certain kinds indicate that the frontal lobes in front of the motor center are the centers of intelligence, ideas, memory, judgment and will. Notwithstanding the fact that the function of a large part of the cortex is not known, it is remarkable that such a considerable part of its area is so well understood.

The cerebrum is a central office to which a multitude of messages concerning the external world is referred. Messages received via the eyes, ears, nose, tongue, skin and muscles are for the most part relayed to it. In the normal brain this does not result in confusion but all is order. These impulses arouse some change within. It is possible that the response will be immediate and may involve many motor outlets. If this is necessary, the apparatus is well equipped to make a complicated response, because of the property of coordination which the brain possesses. It is also possible that there will be no response, for the brain is somehow equipped to sidetrack and inhibit incoming messages.

The brain is able to record and store previous messages received and also its reactions to them. The conduct of the individual may be either immediate response or no response. But this is already getting beyond the boundaries of pure biology. It is the duty of the psychologist to explain further.

Function of Contraction. Animals provided with a skeletal framework, to which voluntary muscles are attached, are capable of more active movements than such animals as the earthworm without such a framework. The bones serve not only as a central support to which the central ends of the muscles are attached, but the outer ends of the muscles are attached to levers (bones) forming the skeletal features of fins or limbs. These muscles (striated) are provided with sensory and motor nerves. Muscle sense organs are located in the muscle. When the muscle contracts, these sense organs are excited and a sensory impulse is sent to the central organ which thus receives information of the condition of contraction and from the mass of such information the animal is able to judge of its position and progress.

On the other hand, motor impulses coming from the central organ to the muscles cause them to contract. Levers are moved in a certain orderly way, and thus locomotion is possible. The muscles of the locomotor organs are arranged in pairs so that when one muscle contracts, another relaxes. All the work is carried out usually in a coordinated fashion. If this were not the case, no progression of the body would be possible.

Muscles are naturally elastic. In the living animal they are always partially contracted and it is known that when they have to actively contract, this preliminary state of partial contraction is advantageous. The amount of contraction depends on the degree of stimulus up to a certain maximum stimulus, beyond which greater stimuli do not produce any greater contractions. Heat increases the height of contractions of isolated muscles and also increases the speed of the contraction, while cold has just the opposite effect. Chemicals and drugs modify normal contractions. Potassium salts depress and calcium salts excite. Caffein and strychnine are stimulants of cardiac muscle.

Muscles are fatigued after repeated contraction. Their store of fuel is consumed and, in spite of more being carried to them by the blood, a change has taken place, rendering this ineffectual. The blood is also flushing out waste products, and the inability of the muscle to continue to contract is probably due to the accumulation in it of waste products. It is believed that the chief fatigue substance is a form of lactic acid peculiar to muscle and called *sarcolactic acid.* Rest is necessary to enable the muscle to return to its normal condition. Anything which favors the carrying away of fatigue products assists in the recovery from fatigue. Taking on of additional fuel does not necessarily help the condition. Warm baths speed up circulation in the muscle. Water taken internally is taken up by the blood and so carried to the muscles and aids in the removal of wastes of catabolism. Muscle fuel has been mentioned. *This is carbohydrate food.* In the blood it is present in the form of a monosaccharid, glucose.

It has been found that furnishing cane sugar to soldiers on a hard day's march quickly energizes them. What probably happens is that the cane sugar is easily changed to glucose in the intestine and is soon supplied to the muscles. Meat is not a good fuel because it is largely protein. As such it is useful chiefly in replacing worn-out protoplasm of muscles. But surprisingly little muscle protoplasm is broken down in muscular activity. The great fuel supply is carbohydrate. Ordinary muscular fatigue is due to muscle deterioration and not to changes in nerves. This does not mean that nerve centers are not fatigable. The amount of energy produced by an active muscle that is available for work compares favorably with the best engines invented by man. In both cases, most of the energy (roughly 75% of the fuel involved) is dissipated in the form of heat.

It must not be forgotten that the muscles of the trunk, though apparently not taking part in locomotion, yet do play a necessary part. Certain of these muscles move the head. Others assist in keeping the body erect. Others assist in chest movements necessary for respiration.

In addition to the muscles attached to bones and used in locomotion, important muscle of another type is found in the wall of the intestine, of the blood vessels, of the ureters, bladder and oviducts. This is *smooth muscle.* Its physiological properties are similar in nature to those of striated muscle. However, it reacts to stimuli much more slowly and it is not under the control of the higher centers, *i.e.*, it is said to be involuntary. This muscle is essential to the circulation of the blood, to the functioning of the glands, to respiration, to the movement of foods through the intestine and to digestion. It is as vitally important as *striated muscle*, which is concerned with physiological processes of adjustment to external stimuli, while smooth muscle takes part in this also in furnishing the striated muscles with blood. Smooth muscle is more actively concerned with those processes which we termed metabolic. Reference has already been made to cardiac muscle.

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CHAPTER XXIV

GENETICS

Introduction. A certain strain of wheat is like its parent in hardness, in gluten quality, in early ripening and in resistance to rust. The offspring of domestic cats are domestic cats; we know beforehand that they will be animals, not plants; Chordates, not Mollusks; Mammals, not Amphibians; Carnivora, not Primates; Felidae, not Canidae and domestic cats, not tigers. The phenomenon of inheritance is observed so frequently as to seem a law of nature. The kitten will grow up into a cat possessing many individual peculiarities of its parents and it will also differ from them in other details. The study of the inheritance of parental characteristics by offspring or among forms related by descent and of variations of these parental characteristics with a view of discovering the laws involved constitutes the special field of biological science called Genetics.

We have already studied many examples of asexual and sexual reproduction. In asexual reproduction, the offspring may be half of a single parent as in the fission of an Amoeba. The characteristics of the parent Amoeba are carried over in toto to the daughter cells. In asexual reproduction, the problems of inheritance are not as complicated as those involving sexual reproduction. However, most of the intensive work in heredity has been concerned with inheritance in sexually reproducing forms.

In sexual reproduction the offspring does not develop from the parents' heart or muscles or liver or from any of the organs of metabolism or adjustment. It develops from a fertilized egg which is the result of the union of an egg cell and a sperm cell. The animal, chordate, mammalian, carnivore, cat-like characteristics of the kitten, referred to above, must have been present in some concrete form in the spermatozoan or egg or both. Cytological and other studies indicate that they are present in both sperm and egg.

Not only are the general characteristics thus represented, but even the peculiar things which mark this animal as a unique individual. There is no other bridge between generations except germ cells. It is evident, therefore, that genetics should include a study of the egg and the sperm.

The organism, from the moment of fertilization onward through life, is subjected to a complex of varying internal and external stimuli, which may modify the course of development. Genetics therefore involves a study of these environmental effects. With the broader questions of the generation of species, *i.e.*, with organic evolution, genetics does not deal directly, but the study throws much light on these problems.

Variations. Differences between individuals of the same species and between offspring of the same parents are well known (Fig. 350). Professor Walter describes variation as "The most unvarying thing in Nature." Bateson, in 1894, published a great mass of such data in his "Materials for the Study of Variation." Examples of variations are: differences in height and weight of persons; differences in the number of grains in different heads of wheat; the number of seeds in different oranges; immunity to disease; eye color and brachydactylism in man. Some are minute and are revealed only by close study, others are gross and

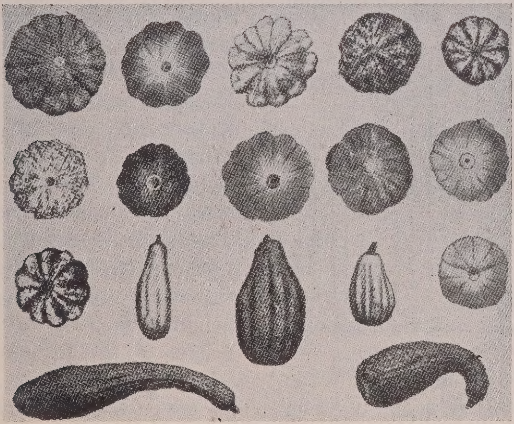

Fig. 350. — Variation in color, shape, size and surface of fruit of summer squash. (From Sinnott, *Botany* — 2nd Edition. McGraw-Hill Book Co. Reprinted by permission.)

easily observable. Some are continuous, as the gradual increase in heights of a great body of men ranging by fractional increments from the shortest to the tallest. Some variations are discontinuous; earthworms differ as to the number of complete segments, not by fractions of a segment. Charles Darwin postulated variations as the basis of his theory of evolution. He recorded many examples of variation in many kinds of animals and plants. He did not explain the cause or origin of variations; and in fact little is known even today concerning this fundamental question.

Galton's Laws. Darwin's cousin, Francis Galton, made the first serious studies in inheritance during the later years of the last century. He collected data of human variations of one sort or another and by a method of mathematical analysis deduced what he claimed were laws of human inheritance. He obtained the height of 204 English parents of graduated statures and their 928 mature children. The average height of females is less than that of males by 8%, so Galton multiplied each female height by 1.08 to bring female height to the same standard as male height. He then added the height of the father to the corrected height of mother and divided the result by two. This gave him one number for the height of the two parents. He arranged parental heights in classes. The results in inches were as follows:

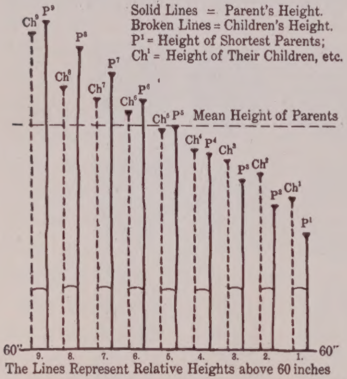

FIG. 351. — Diagram illustrating Galton's Law of Filial Regression.

	I	II	III	IV	V	VI	VII	VIII	IX
Parental height . .	64.5	65.5	66.5	67.5	68.5	69.5	70.5	71.5	72.5
Height of children .	65.8	66.7	67.2	67.6	68.3	68.9	69.5	69.9	72.2

One notes that the children of the shortest are taller than their parents and also that the children of the tall parents are shorter than their parents. This indicates a tendency toward the average height, and is known as *Galton's Law of Filial Regression* (Fig. 351), which is stated thus: Average parents produce average offspring: tall parents produce tall children, short parents produce short children, but the children are not as tall or as short as their parents, that is, there is a tendency toward the average condition; the children inherit the parental characteristics in a less divers degree. Galton would have this law apply to inheritance of all sorts of characters, mental as well as physical. He made a more definite assertion derived from mathematical consideration of the results, namely, that children show only two thirds of the parental deviation from the racial average. By his statistical methods he arrived at another general conclusion known as the *Law of Ancestral Inheritance* (Fig. 352). According to this, he asserted that the two parents contributed one half of the total inheritance of the child; the four grandparents, one fourth; the eight great-grandparents, one eighth, etc.

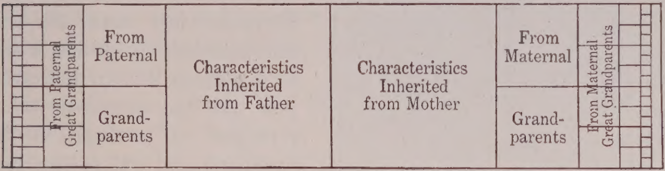
From Paternal Great Grandparents
From Paternal
Grand-parents
Characteristics Inherited from Father
Characteristics Inherited from Mother
From Maternal
Grand-parents
From Maternal Great G. Grandparents

FIG. 352. — Diagram illustrating Galton's Law of Ancestral Inheritance.

Statistical Methods. Such methods of mathematical analysis have been extended, since Galton's time, by his successor Karl Pearson of England and others. These methods, which constitute the science of biometry, have been applied to the solution of problems of heredity, evolution and other biological questions. The methods are especially applicable to the study of quantitative inheritance which apparently does not lend itself, on account of complexity, to analysis by Mendelian methods to be explained presently. It does not follow, however, that on this account the information gained is necessarily valuable.

Let us study a possible example of how these methods might be applied. Suppose we wish to study, by the statistical method, the inheritance of ray (ridges) numbers of the common scallop, *Pecten*. We must first devise a method by which we can accurately measure that character in parents and offspring, both representative of all scallops. We collect a large number of scallop shells and sort them out into groups of different ray numbers.

The accompanying photograph (Fig. 353) illustrates such a study. Of 135 shells examined, there were 5 shells that had 15 rays; 30 that had 16 rays; 76 that had 17 rays; 20 that had 18 rays and 4 that had 19 rays. We conclude that so far as this character is concerned, the ray number is 17. That is the biological average or mode. We now note that a heavy black line is drawn about the upper ends of the various shell groups. This is the 'variation curve' for this particular experiment. It represents the variation in ray numbers of the scallops studied. The biometrician has devised mathematical formulae which he can apply here to determine how well the specimens taken represent *all scallops.* If his mathematical test proves that our figure is representative of all scallops of this species, then he claims that the biological average for ray numbers in the common scallop is 17. Now we could study the offspring similarly and determine inheritance of ray number. Large numbers of cases are used in statistical studies and the conclusions are generalizations that apply to large numbers. They do not concern individual cases.

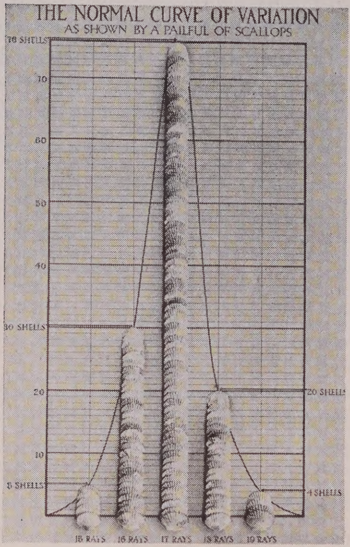

FIG. 353. — Normal curve of variation in rays on scallop shells. (Courtesy of American Museum of Natural History.)

But the practical breeder is not satisfied with generalizations. The farmer is more interested in the milk production of a particular cow or in the performance of his own small herd, but not so much in what that breed does. He may have in *his* herd some of the poorest producers, those down at the lowest end of the variation curve and he would not be inclined to keep those particular cows simply because statistical methods had demonstrated the breed to be a superior milk-producing type. He is not interested in generalizations. He wants something more specific.

Another application of these methods is that of ascertaining the degree of correlation between two different sets of facts. For example, as cited by Shull: "High egg laying in a certain breed of fowl is correlated with the paleness of the yellow color of the exposed parts of the skin." In arriving at an idea as to the degree of correlation, the student determines the *coefficient of correlation.* This ranges between 0.0 and 1.0. A number below 0.5 indicates little correlation, but between 0.5 and 1.0 the number is significant of correlation, and this becomes more probable as the coefficient approaches 1.0. Students interested in biometry are referred to treatises which explain its methods and the application of them.

Fig. 354. — Gregor Mendel. (Courtesy of *Genetics*.)

Mendelism. — About the year 1900 a number of investigators became interested in specific breeding experiments in the endeavor to ascertain whether laws of inheritance were operative when particular qualities were kept under observation. Three pioneers were DeVries of Holland, von Tschermak of Austria and Correns of Germany. These men found that this method had been employed nearly forty years before by an earlier worker, Gregor Mendel (Fig. 354), a priest living at Brünn, Austria. Just after the rediscovery, in 1900, of Mendel's paper, other workers at once appeared, such as Bateson in England and Davenport and Castle in America. Mendel had studied science at the University of Vienna. About 1857 he began an experimental inquiry into heredity and worked painstakingly and successfully for eight years. As Castle says, "His keen analytical mind enabled him to plan and execute the most original and fruitful investigations on heredity ever completed." Father Mendel published his epoch-making results in the journal of the local natural history society. He sent an account of his work to the botanist, Professor Nägeli, who was more interested in other things just then and paid no real attention.[1] Charles Darwin had published the epoch-making " Origin of Species " but a few years before. It is interesting to speculate as to what would have resulted for science had Darwin known Mendel's work.

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[1] Nägeli wrote Mendel that the latter's results *were theoretically impossible!*

Mendel worked with varieties of garden peas. There is little variation within each variety because they are self-fertilized. Pollen from the stamens produces sperm cells which fertilize the egg cells in the ovaries of the same flower. Mendel noted that each variety had distinctive characters. One variety was tall, another was dwarf; one variety had smooth-coated seeds, another had wrinkled seeds; one had green-colored seeds, another had yellow seeds. Moreover, there was practically no gradation between green and yellow, between smooth and wrinkled, between tall and dwarf.

The offspring of dwarf peas were dwarfs and those which had green seeds produced green-seeded offspring uniformly and without variation. Mendel worked with seven pairs of contrasting or alternative characters or *allelomorphs*, as they are called. These are:

1. Form of the ripe seeds, *round* or *wrinkled.*
2. Color of the material in the cotyledons, *yellow* or *green.*
3. Color of the seed coat, *white* or *gray.*
4. Form of the ripe pods, *inflated* or *constricted.*
5. Color of the unripe pods, *green* or *yellow.*
6. Position of the flowers, *axial* or *terminal.*
7. Length of the stem, *tall* or *dwarf.*

At first he worked with each pair of allelomorphs separately and kept accurate records.

To cross or hybridize them he had to proceed as follows: For example, to cross a *tall* with a *dwarf* pea, it was necessary to remove all the stamens from *tall* plant flowers and place on their stigmas pollen from *dwarf* plant flowers or vice versa. He found that it made no difference which was taken as female or male, so far as inheritance was concerned. To understand his work a simple typical experiment is described. He crossed *tall* with *dwarf* peas. The resulting seed from this parental generation were all carefully saved and planted the next spring. They developed into *tall* pea plants exclusively. If there was any dwarfness about them, it was hidden. So Mendel called tallness *dominant* and dwarfness *recessive.* During the second summer, he crossed these *tall hybrid* plants, carefully collecting the seeds as before. He planted them during the third summer, and *tall* and *dwarf* plants appeared.

He counted the two lots. There were about three times as many *talls* as *dwarfs*. The actual numbers were 787 *talls* and 277 *dwarfs*. On intercrossing the *dwarfs*, the resulting plants during the fourth summer were all *dwarfs*. He crossed these again, and the next summer they were all *dwarfs* again and the result continued to be the same. This showed that the first *dwarfs* to reappear were pure recessives like their grandparents.

But what about the *hybrid talls?* Mendel inbred them. In the third summer the population contained some *dwarfs* again. The first *hybrid talls* could not have been all pure *talls* or pure dominants because on inbreeding they produced some recessives. But, nevertheless, they might have contained some pure dominants like the *original talls* and also some *hybrids* like the parents. This proved to be the case, because Mendel was able to show that the *talls* in the second filial generation consisted of one third pure dominants and two thirds hybrids or impure dominants. Of the whole population of the second filial generation, this meant that, $\frac{1}{4}$ were pure dominant, *tall;* $\frac{1}{2}$ *hybrid tall* or impure dominant and $\frac{1}{4}$ *dwarf* or pure recessive.

Similar proportions obtained when Mendel interbred the other pairs of characters. On crossing yellow-seeded peas with green-seeded he obtained, in the second filial generation, 6022 yellow peas to 2001 green peas, and in another experiment, 5474 round seeds to 1850 wrinkled seeds or about a proportion of 3 to 1 in each case, as before when hybrids were crossed. The first group proved to be $\frac{1}{4}$ pure yellow, $\frac{1}{2}$ hybrid yellow, $\frac{1}{4}$ pure green and in the latter experiment, $\frac{1}{4}$ pure round; $\frac{1}{2}$ hybrid round and $\frac{1}{4}$ pure wrinkled. A dominant character may be labeled by the capitalized first letter of the word denoting that character and the recessive allelomorph by the small letter form of the *same* letter, *i.e.*, Tall — T and dwarf — t.[1]

Mendel's Laws. As a result of these experiments, Mendel was able to explain the phenomena and came to the conclusion that laws or principles of inheritance were involved. These are now called the Mendelian Laws.

1. *Unit Characters.* Mendel thought of the organism as an aggregate of distinct and separate *unit characters*, such as tallness,

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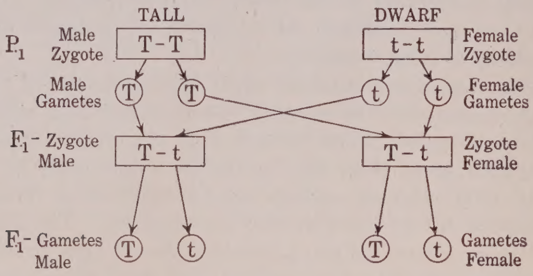
[1] Some workers prefer the reverse of this, *i.e.*, to use the *small* initial letter of the recessive for the recessive and the capital form of the same letter for the dominant, *i.e.*, in this case "d" = dwarf and "D" = tall.

green cotyledons and smooth seed coat. Since a hybrid tall-dwarf pea, on being interbred, produced both tall and dwarf offspring, he believed that these *hybrids* contained both tall and dwarf unit characters although they *looked* tall. Then he conceived that each body cell of all individuals contained a double set of every type of unit character, but that gametes contained only single unit characters. That is, in modern terminology the body cells of the tall pea contained a double set of *tall* unit characters or, TT; and their gametes would all be merely T. Cells of dwarf plants would contain a double set of dwarf unit characters, *i.e.*, tt, but their gametes, only one, *i.e.*, t. When a " T " gamete and a " t " gamete united, the zygote would be " Tt " or the hybrid *tall-dwarf*. Their male gametes would be equal numbers (50% each) of " T " and " t " and the female gametes also 50% " T " and 50% " t." We can represent the breeding experiment in diagram form as shown below:


TALL
DWARF
P_1
Male Zygote
T-T
t-t
Female Zygote
Male Gametes
T
T
t
t
Female Gametes
F_1- Zygote Male
T-t
T-t
Zygote Female
F_1- Gametes Male
T
t
T
t
Gametes Female

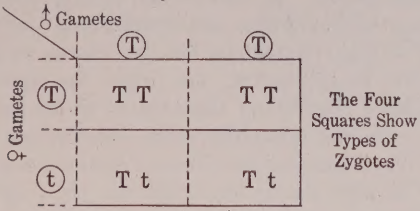
Now interbreed the F_1 hybrids which have equal numbers of T and t gametes. What would happen? According to the " laws " of probability, the union of these, in fertilization, would be 25% " TT "; 25% " Tt "; 25% " tT " and 25% " tt," or what is the same thing: 25% " TT "; 50% " Tt " and 25% " tt." The hypothesis can be diagrammed as follows.

Female Gametes

Male Gametes	Ⓣ	ⓣ
Ⓣ	T T	T t
ⓣ	T t	t t

The Four Squares
show types
of Zygotes

Mendel's actual breeding experiment agreed with this hypothetical result. Now if the hypothesis is correct, it can be tested by crossing a *pure* tall with a *hybrid* tall. The experiment would be figured as follows.



Let us suppose that the male gametes come from a pure tall and female gametes come from a hybrid tall.[1] Accordingly, 50% of the offspring should be TT and 50%, Tt. But mere inspection of the progeny would not reveal this since all talls look alike. Since all are, at any rate, tall, the experiment gives that much information for theoretically that is what they should be.

But a more satisfactory experiment than the last can be made. We can back cross a hybrid "Tt" with a pure dwarf, "tt." (See Fig. 359.) The student can construct the diagram of such an experiment and can see that the results should be 50% "Tt" and 50% "tt." Actual experiment confirmed this. Mendel's explanation as to the dual or *diploid* nature of the body in unit character representation and the simple or *haploid* condition in the gametes has been accepted by geneticists. If the student refers back to the description of the behavior of the chromosomes in gamete formation (Fig. 298 *A*), he will see that the reduction divisions confirm the theoretical explanation given by Mendel. According to the Mendelian theory, if the somatic cells contain a duplex set of the same unit character, for example "TT," the organism is *homozygous* with regard to that character. If the somatic cells contain both of the alternative characters, for example "Tt," then the organism is *heterozygous* as to that character.

It should be noted that if contrasting characters which had been inbred in the first filial generation (F_1) reappear unchanged in the second filial generation (F_2), such results indicate the *unit character* quality of such traits in heredity. The organism is an aggregation of its unit characters.

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[1] It makes no difference which sex is pure or hybrid. The important thing is that one parent is *pure* tall (TT) and the other *hybrid* tall (Tt).

♂ = male; ♀ = female.

2. *Segregation.* A second principle or law developed by Mendel is that of segregation. If two forms having contrasting unit characters, *i.e.*, allelomorphs, are hybridized, the hybrid may resemble one of these characters, but two classes of offspring will reappear in the F_2 generation, *i.e.*, when the hybrids (F_1) are inbred. We have studied an explanation as to how this takes place. Body cells and primordial germ cells contain pairs of unit characters. When gametes are formed, each receives *one member* of each *pair* of unit characters which are thus *segregated* when sex cells are formed. If both members of a factor pair are alike, *i.e.*, if the zygote is homozygous, then there will be but one type of gamete; but a hybrid, whose cells are heterozygous, will produce gametes of two kinds. Individual unit characters are *segregated* when gametes are formed.

3. *Dominance.* A third law of Mendel is that of dominance. For example, hybrids of tall and dwarf peas appear tall; hybrid round-seeded by wrinkled-seeded peas are round-seeded; yellow peas by green peas hybrids appear yellow. Tall, round, yellow are respectively dominant over dwarf, wrinkled, green. When the hybrids are interbred, the character which was latent in the F_1 generation reappears, and such characters are termed recessive, *i.e.*, dwarf, wrinkled and green.

In order to understand Mendel's theory better, it will be worth while to work out a simple problem somewhat more completely. Let us work with another pair of characters chosen by Mendel. In the following diagrams, oblongs represent zygotes and circles outside of oblongs represent gametes; the letters inside the circles are abbreviations for unit characters being tested; the capital letter " R " represents a dominant character and the small letter " r " represents the recessive character allelomorphic to " R." The following experiments have to do with hybridizing peas that have *round* (*R*), *i.e.*, smooth, ripe seeds with a variety whose seeds are *wrinkled* (*r*). Let us divide the problem into several steps.

(*A*) In Fig. 355, we have a diagrammatic representation of a preliminary but necessary experiment. The purpose of this is to prove the purity of the strain. Both parents have round seeds and the seeds of the offspring are round also. If we interbred the latter, we would find the same results. The diagram represents Mendel's idea of the disposition of the unit characters in parents; in gametes and in offspring — namely, diploid in parents; haploid in gametes and diploid again in offspring. Moreover, parents and offspring are homozygous. Repeated inbreeding should give the same results.

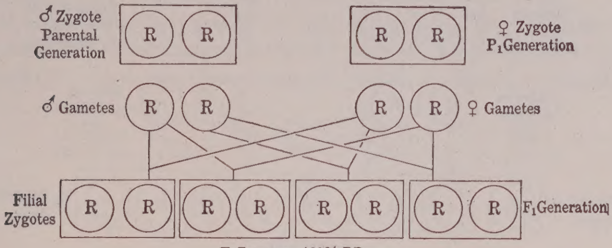

♂ Zygote
Parental
Generation
R
R
R
R
♀ Zygote
P_1Generation
♂ Gametes
R
R
R
R
♀ Gametes
Filial
Zygotes
R R
R R
R R
R R
F_1Generation
F_1 Zygotes = 100% RR.

FIG. 355. — Breeding round-seed peas with round-seed peas.

(*B*) Let us now establish proof of the purity of the other allelomorph, namely, the wrinkled peas. The experiment as explained by Mendel is represented by Fig. 356. If both parents are homozygous for "wrinkled," it is evident that the offspring must also be like them. Repeated interbreeding gives no other results, provided the strain is as represented here.

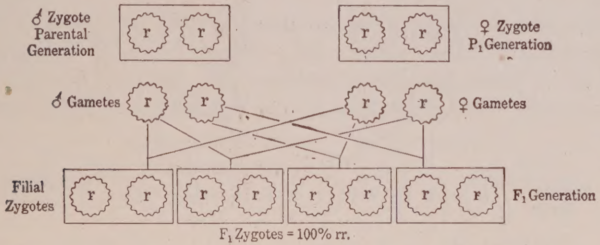

♂ Zygote
Parental
Generation
r
r
r
r
♀ Zygote
P_1Generation
♂ Gametes
r
r
r
r
♀ Gametes
Filial
Zygotes
r r
r r
r r
r r
F_1 Generation
F_1 Zygotes = 100% rr.

FIG. 356. — Breeding wrinkled-seed peas with wrinkled-seed peas.

(*C*) Now let us cross *round* seeds with *wrinkled* seeds, using for one parent, material tested as in experiment *A*, and for the other parent material tested as in experiment *B*. We can use round seed male and wrinkled seed female or vice versa. Fig. 357 represents the experiment as Mendel explained it. The gametes of the round parent are all round and those of the other parent are all *wrinkled.* When fertilization takes place, in every filial zygote there is a combination of a round and a wrinkled unit character. But since all the seeds appear to be round, we conclude that round is dominant and wrinkled is recessive. Moreover, all the filial zygotes are heterozygous because each now carries a pair of allelomorph characters.

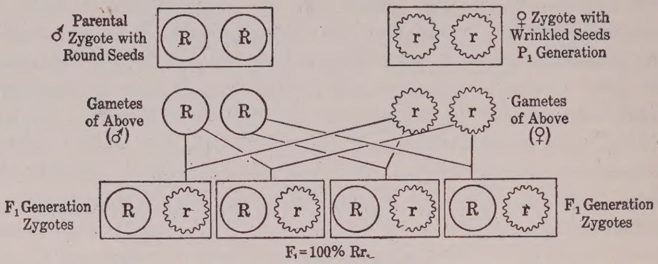

Parental
♂ Zygote with
Round Seeds
R
R
r
r
♀ Zygote with
Wrinkled Seeds
P_1 Generation
Gametes
of Above
(♂)
Gametes
of Above
(♀)
F_1 Generation
Zygotes
R r
R r
R r
R r
F_1 Generation
Zygotes
F_1=100% Rr.

FIG. 357. — Breeding round-seed peas with wrinkled-seed peas.

(*D*) We will now interbreed these hybrids. The theoretical representation of such an experiment is shown in Fig. 358. Each parent produces two kinds of gametes and in equal numbers. The chances are, that in fertilization four combinations will be made as shown in the diagram. One (*a*) out of every four zygotes will be homozygous round; two (*b* + *c*) will be heterozygous round-wrinkled and one (*d*) will be homozygous wrinkled. Actual experimentation gives results as figured. Continued inbreeding of the homozygous round would produce only homozygous round, as indicated in Fig. 355. Also continued inbreeding of the

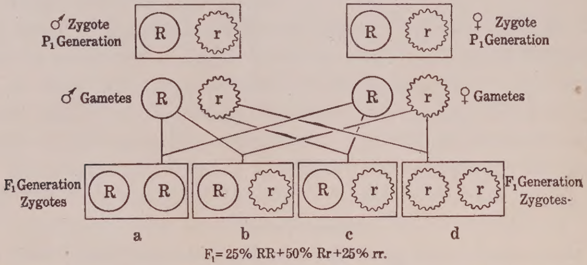

♂ Zygote
P_1 Generation
R r
R r
♀ Zygote
P_1 Generation
♂ Gametes
R
r
R
r
♀ Gametes
F_1 Generation
Zygotes
R R
R r
R r
r r
F_1 Generation
Zygotes
a
b
c
d
F_1= 25% RR+50% Rr+25% rr.

FIG. 358. — Breeding hybrid round-wrinkled seed peas with hybrid round-wrinkled seed peas.

recessive homozygous wrinkled would produce only homozygous wrinkled, as shown in Fig. 356. Experiment confirms this. But suppose we interbred heterozygous round-wrinkled with heterozygous round-wrinkled, then what? Our results should be as indicated by this same Fig. 358, and they prove to be so.

(*E*) Now we can test this hypothesis further. Suppose we interbreed a homozygous wrinkled with a heterozygous round-wrinkled. Since one (homozygous) parent is like the original, as shown in Fig. 356, and the other parent a hybrid, such an experiment would be called " back crossing." Fig. 359 represents this test. Here the hybrid is crossed with a recessive homozygous wrinkled. The results should be as presented and they prove to be so.

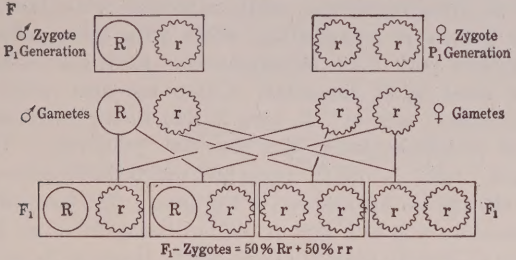

F
♂ Zygote P$_1$ Generation
R
r
r
r
♀ Zygote P$_1$ Generation
♂ Gametes
R
r
r
r
♀ Gametes
F$_1$
R r
R r
r r
r r
F$_1$
F$_1$– Zygotes = 50 % Rr + 50 % r r

FIG. 359. — Back crossing homozygous recessive wrinkled-seed peas with hybrid (heterozygous) round-wrinkled seed peas.

(*F*) Or we can cross a heterozygous round-wrinkled with a homozygous dominant round. The results should be as shown in Fig. 360, and they are. The student may find it useful to conduct similar breeding experiments *on paper*, using the other allelomorphs

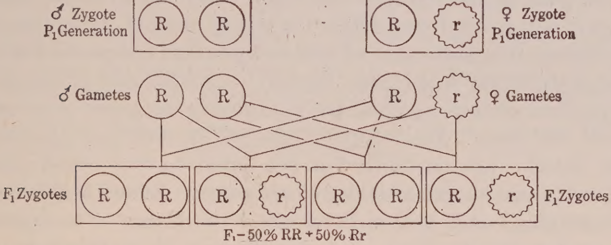

♂ Zygote P$_1$ Generation
R R
R r
♀ Zygote P$_1$ Generation
♂ Gametes
R
R
R
r
♀ Gametes
F$_1$ Zygotes
R R
R r
R R
R r
F$_1$ Zygotes
F$_1$ – 50% RR + 50% Rr

FIG. 360. — Back crossing homozygous dominant round peas with hybrid (heterozygous) round-wrinkled seed peas. All *appear* round.

that Mendel worked with. Experiment F does not give such analytical information as experiment E and a study of the results corroborates this.

Factor Hypothesis: the Gene. The expression "unit character" was somewhat indefinite. As work along these lines progressed, after 1900, this indefiniteness gave way to a clearly defined conception of the so-called *unit character*. The term has been succeeded by the word *gene*. A gene, according to present ideas, is an ultramicroscopic, multi-molecular protoplasmic body, probably protein in composition, which with other genes makes up the greater part of the chromosomes. Each gene is the *determiner* of some adult character. Genes are also called *factors*. The character "tallness" in peas is due to the presence in the zygote of a definite body, the gene for "tallness." The gene itself is not "tall" — but the plant into which that zygote develops will be tall, due to the presence of the gene. The conception that the gametes uniting in a zygote contain the genes of all the characteristics of an individual is known as the *theory of the gene* or the *factor hypothesis*.

For example, the following are believed on good evidence to be *factors* in human inheritance — a certain type of color blindness, immunity to disease, blue eyes, red hair.

Professor Biffen in England found by experiment that the following are factors in wheat: beardlessness, red grain, early ripening, thick stem, immunity to rust. In other words each of the above cited characters are represented in the gametes by definite particles called "genes."

Independent Assortment of Factors. A Dihybrid Ratio. This is an extension of the law of segregation. Mendel investigated several pairs of allelomorphs and found when he carried on experiments in which two forms differed in two or more of these, that the inheritance of any one pair of allelomorphs was *independent* of the inheritance of any other pair (Fig. 361). Inheritance of stature is independent of seed color and both of these independent of smoothness of seed coat. An example of this will be cited and studied in some detail. Let us inbreed a pea plant having round-yellow seeds with one having wrinkled-green seeds. Round is dominant over wrinkled and yellow dominant over green. The hybrids will appear round-yellow. Let us now cross these *hybrid* round-yellows. We find four classes of offspring in *definite* proportions.

$\frac{9}{16}$ round-yellow; $\frac{3}{16}$ round-green; $\frac{3}{16}$ wrinkled-yellow; $\frac{1}{16}$ wrinkled-green. Recall that when round-wrinkled hybrids are crossed, the F_2 generation would be $\frac{3}{4}$ round to $\frac{1}{4}$ wrinkled.

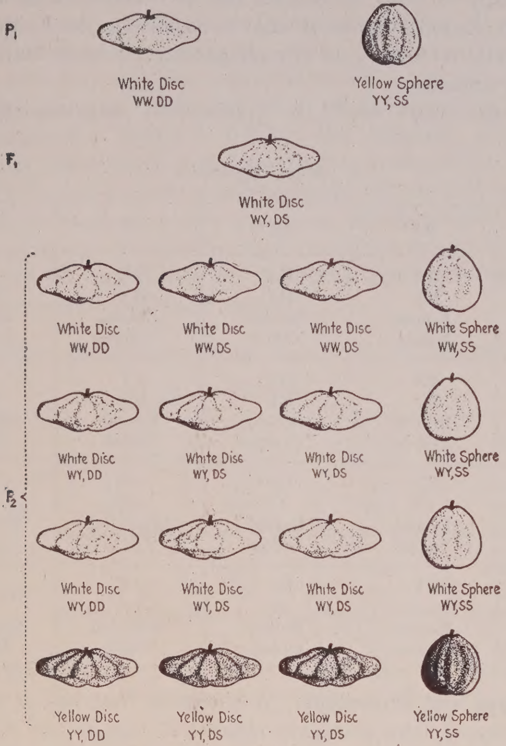

P1
White Disc
WW. DD
Yellow Sphere
YY, SS
F1
White Disc
WY, DS
F2
White Disc
WW, DD
White Disc
WW, DS
White Disc
WW, DS
White Sphere
WW, SS
White Disc
WY, DD
White Disc
WY, DS
White Disc
WY, DS
White Sphere
WY, SS
White Disc
WY, DD
White Disc
WY, DS
White Disc
WY, DS
White Sphere
WY, SS
Yellow Disc
YY, DD
Yellow Disc
YY, DS
Yellow Disc
YY, DS
Yellow Sphere
YY, SS

FIG. 361. — Mendelian dihybrid ratio. Two pairs of characters are involved. In summer squashes, *disc* shape is dominant over *sphere* shape and *white* color over *yellow*. White disc crossed with yellow sphere gives an F_1 generation, in which all offspring are white disc. When these hybrids are interbred, the F_2 generation consists of about: $\frac{9}{16}$ white disc; $\frac{3}{16}$ white sphere; $\frac{3}{16}$ yellow disc and $\frac{1}{16}$ yellow sphere. (From Sinnott, *Botany — Principles and Problems*, Revised edition. McGraw-Hill Book Co. Reprinted by permission.)

When hybrid yellow-greens are crossed, the F_2 generation would be $\frac{3}{4}$ yellow to $\frac{1}{4}$ green. Now if the theory of independent assortment is true and if both crossings are made simultaneously, we should find $\frac{3}{4}$ round × $\frac{3}{4}$ yellow, or $\frac{9}{16}$ round-yellow; $\frac{3}{4}$ round ×

$\frac{1}{4}$ green, or $\frac{3}{16}$ round-green; $\frac{3}{4}$ yellow × $\frac{1}{4}$ wrinkled, or $\frac{3}{16}$ yellow-wrinkled; $\frac{1}{4}$ green × $\frac{1}{4}$ wrinkled, or $\frac{1}{16}$ green-wrinkled. But this tells us nothing of the genetic constitution of these forms. We can, theoretically at least, determine this by diagramming according to the Mendelian hypothesis what took place in the F_2 generation. There would be four types of male gametes and four similar types of female gametes.

The experiment would be represented diagrammatically as follows:

MALE GAMETES

FEMALE GAMETES

	RY	Ry	rY	ry
RY	RY RY Round Yellow	Ry RY Round Yellow	rY RY Round Yellow	ry RY Round Yellow
Ry	RY Ry Round Yellow	Ry Ry Round Green	rY Ry Round Yellow	ry Ry Round Green
rY	RY rY Round Yellow	Ry rY Round Yellow	rY rY Wrinkled Yellow	ry rY Wrinkled Yellow
ry	RY ry Round Yellow	Ry ry Round Green	rY ry Wrinkled Yellow	ry ry Wrinkled Green

Genotype and Phenotype. Any zygote that has at least *one gene* for round (the dominant character) will *appear* round and any zygote that has at least one gene for yellow will *appear* yellow. As previously estimated, *these* sixteen combinations fall into four groups; *i.e.*, $\frac{9}{16}$ round-yellow; $\frac{3}{16}$ round-green; $\frac{3}{16}$ wrinkled-yellow and $\frac{1}{16}$ wrinkled-green. Thus, there are four different lots so far as *external appearance* goes. These are called *phenotypes*. However, if we examine the gene composition of *all* the members of any one group we find different combinations of genes, although all in the group have the same external appearance. For example, in the round-yellow phenotype group we find the following different gene combinations: RRYY: RRYy: RrYY: RrYy.

These are called *genotypes*, *i.e.*, in this case the phenotype round-yellow has four genotypes. The round-green phenotype contains the following genotypes, RRyy : Rryy. The wrinkled-yellow phenotype has two genotypes, rrYY, rrYy. Finally, the wrinkled-green is a phenotype *and* a genotype also. It is more important to know the genotype rather than the phenotype because if we interbred phenotypes, we could not necessarily produce similar offspring. For example, if we interbred the Round-yellow phenotypes RRYY × RRYy, the offspring would all appear round yellow while if we interbred the round-yellow phenotypes RrYY × RrYy, there would be round yellows and wrinkled yellow. If we interbred similar genotypes, all the progeny would be like the parents. To test this we will diagram two more experiments. First let us inbreed the following genotypes belonging to the round-yellow phenotype group.

GENETIC COMPOSITION OF MALE ZYGOTE — RRYY

MALE GAMETES

GENETIC COMPOSITION OF FEMALE ZYGOTE—RRYy

FEMALE GAMETES

	RY	RY	RY	RY
RY	RY RY Round Yellow	RY RY Round Yellow	RY RY Round Yellow	RY RY Round Yellow
Ry	RY Ry Round Yellow	RY Ry Round Yellow	RY Ry Round Yellow	RY Ry Round Yellow
RY	RY RY Round Yellow	RY RY Round Yellow	RY RY Round Yellow	RY RY Round Yellow
Ry	RY Ry Round Yellow	RY Ry Round Yellow	RY Ry Round Yellow	RY Ry Round Yellow

The phenotype is named in each square.

In this case two different genotypes of the same phenotype class are interbred. All the offspring are *similar phenotypically* to the parents, for all have at least one dominant factor for shape, *i.e.*, round and also at least one dominant factor for color, *i.e.*, yellow. And yet the same two genotypes still appear, *i.e.*, RRYY and RRYy. But promiscuous inbreeding of *any similar pheno-*

types will not *always* give us the same results. This is shown in the second case. Let us now interbreed two other zygotes of the same phenotype class as before but which are different genotypes, namely, RrYY and RrYy.

GENETIC COMPOSITION OF MALE ZYGOTE — RrYY

MALE GAMETES

GENETIC COMPOSITION OF FEMALE ZYGOTE — RrYy

FEMALE GAMETES

	RY	RY	rY	rY
ry	RY ry Round Yellow	RY ry Round Yellow	rY ry Wrinkled Yellow	rY ry Wrinkled Yellow
rY	RY rY Round Yellow	RY rY Round Yellow	rY rY Wrinkled Yellow	rY rY Wrinkled Yellow
Ry	RY Ry Round Yellow	RY Ry Round Yellow	rY Ry Round Yellow	rY Ry Round Yellow
RY	RY RY Round Yellow	RY RY Round Yellow	rY RY Round Yellow	rY RY Round Yellow

The phenotype is named in each square.

In this example two different genotypes of the same phenotype class are interbred. In this case the *offspring* belong to *two* phenotype classes, namely, round-yellow and wrinkled-yellow. It will be noted that all zygotes have at least one factor for yellow which is dominant. Some of the zygotes are wrinkled because some classes of male *and* female gametes *both* carry this recessive factor.

A Trihybrid Ratio. In the next place let us diagram what would be produced if we inbred two parents, each of which is a hybrid tall-dwarf, yellow-green and round-wrinkled. The table on the following page shows the results.

Phenotypes are as follows: Out of the 64 classes of zygotes there are $\frac{27}{64}$ RYT; $\frac{9}{64}$ RYt; $\frac{9}{64}$ RyT; $\frac{9}{64}$ rYT; $\frac{3}{64}$ Ryt; $\frac{3}{64}$ rYt; $\frac{3}{64}$ ryT; $\frac{1}{64}$ ryt. There are 27 different genotypes.

TRIHYBRID RATIO

Trihybrid Male Zygote's Genetic Composition = TYRtyr

MALE GAMETES

Genetic Composition of Female Trihybrid Zygote — TYRtyr

FEMALE GAMETES

	TYR	TyR	TYr	Tyr	tYR	tyR	tYr	tyr
TYR	TYR TYR	TyR TYR	TYr TYR	Tyr TYR	tYR TYR	tyR TYR	tYr TYR	tyr TYR
TyR	TYR TyR	TyR TyR	TYr TyR	Tyr TyR	tYR TyR	tyR TyR	tYr TyR	tyr TyR
TYr	TYR TYr	TyR TYr	TYr TYr	Tyr TYr	tYR TYr	tyR TYr	tYr TYr	tyr TYr
Tyr	TYR Tyr	TyR Tyr	TYr Tyr	Tyr Tyr	tYR Tyr	tyR Tyr	tYr Tyr	tyr Tyr
tYR	TYR tYR	TyR tYR	TYr tYR	Tyr tYR	tYR tYR	tyR tYR	tYr tYR	tyr tYR
tyR	TYR tyR	TyR tyR	TYr tyR	Tyr tyR	tYR tyR	tyR tyR	tYr tyR	tyr tyR
tYr	TYR tYr	TyR tYr	TYr tYr	Tyr tYr	tYR tYr	tyR tYr	tYr tYr	tyr tYr
tyr	TYR tyr	TyR tyr	TYr tyr	Tyr tyr	tYR tyr	tyR tyr	tYr tyr	tyr tyr

We observe, from a comparison of the types of experiments cited, namely, (*a*) those in which *one pair* of characters alone was considered; (*b*) where *two* allelomorphs were used in the same experiment and (*c*) where *three* allelomorphs were inbred in the same experiment, that the number of different types of gametes is greater in each successive case; the number of phenotypes increases and also the number of genotypes. Let us represent the number of allelomorphs or factor pairs by the letter "n." The following formula is useful. The number of kinds of gametes (male or female) is 2^n; the number of phenotypes is 2^n; the number of genotypes is 3^n.

Let us take the example in which three allelomorphs were used in a single experiment. This is a trihybrid ratio. In this case we crossed two plants that are each hybrid, *i.e.*, RYTryt × RYTryt. The number of factor pairs is three, namely, R-r; Y-y; T-t. According to the formula, there must be 2^3 gametes of each sex, or 8; there must be 8 phenotypes and 27 genotypes. The preceding table confirms this.

Mendel worked with seven pairs of allelomorphs. If he obtained hybrids embodying combinations of all of the above, then there would have been 2^7 or 128 different kinds of gametes; there would have been as many phenotypes and 2187 or 3^7 genotypes.

It is said that man possesses 24 pairs of chromosomes. Theoretically each chromosome carries many genes. If each chromosome pair carried only one distinctive allelomorphic pair, according to the above formulae there would be 16,777,216 different male and female gametes and just as many phenotypes and 3^{24} genotypes. But chromosomes are far, far more complicated than this, so that *great variation* in children follows. Children are *like* their parents in *some* respects and *unlike* them in *other* respects.

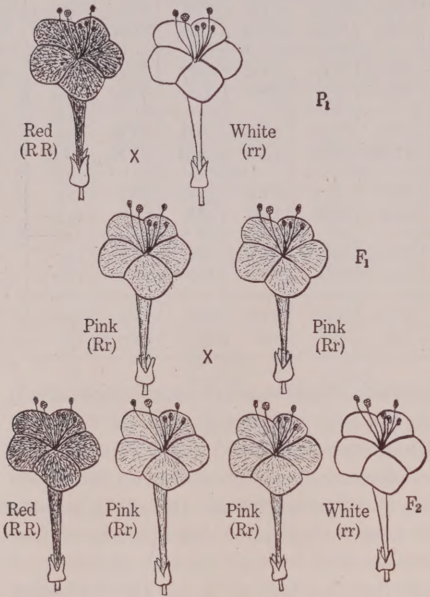


FIG. 362 *A*. — Lack of Dominance — illustrated by interbreeding Red and White Four O'clocks

Presence-Absence Hypothesis, or Absence of Dominance. Many of the earlier simple conceptions of Mendel have been modified, due to experiments with a great variety of plants and animals. Exceptions to the so-called law of dominance were soon found by later workers, and now it is not considered essential to Mendelian theory. For example (Fig. 362 *A*), when *red* Four O'clock plants are crossed with *white* Four O'clocks, the flowers of the hybrids are *pink*, showing that the law of dominance does not hold here. When the hybrid pinks are inbred, there are three classes of offspring, namely, 25% reds; 50% pinks; 25% whites.

To explain this, the presence-absence hypothesis was advanced. According to this idea, red is due to the presence of a double set of color-determining factors, *i.e.*, R-R; while white is due to the absence of these, *i.e.*, r-r. A zygote that contains R-R in its body cells has red flowers; one that has r-r in its body cells is white flowered and one that has the combination R-r will be pink flowered. We can see that if R-r is crossed with R-r, the resulting offspring will be 25% R-R; 50% R-r; 25% r-r, as stated above.

Another early case that appeared was that of the Blue Andalusian fowl. Breeders could never get this to breed true and were at a loss to know why. Breeding experiments after the Mendelian fashion (Fig. 362 *B*) revealed the fact that the Blue Andalusian is a hybrid between certain black and white parent breeds. The case is similar to the above Four O'Clock example. Other cases examined indicated that although dominance of a sort is present it differs in degree and that other factors sometimes influence dominance.

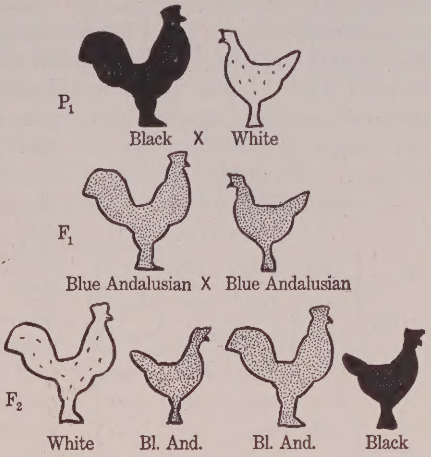
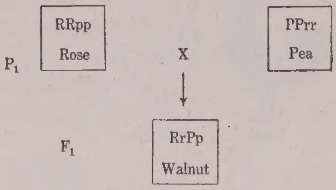


FIG. 362 *B*. — Lack of Dominance in Blue Andalusian Fowls.

Modification of Factors. Not all breeding experiments show as simple definite results as those of Mendel. It has been found that factor pairs in combination with each other in some cases produce a modification of what occurs when inbred separately.

Certain breeds of poultry have what is known as a "rose" comb; other breeds, a "pea" comb; and still others, a "single" comb. Each type breeds true. But when "rose" was crossed with "single," there was a distinct separation into two classes as follows: $\frac{3}{4}$ "rose" and $\frac{1}{4}$ "single," the monohybrid ratios already familiar to us. Again, when "pea" was crossed with "single," the result was $\frac{3}{4}$ "pea" and $\frac{1}{4}$ "single." "Rose" is dominant over "single" and "pea" is dominant over "single" also.

But Bateson and Punnett found that when they crossed " rose " and " pea," neither proved to be dominant but a new type of comb called " walnut " appeared. This had previously been found in an unrelated breed of fowls. Then they inbred the hybrid " walnuts," and in the F_2 generation there were $\frac{9}{16}$ " walnut," $\frac{3}{16}$ " rose," $\frac{3}{16}$ " pea " and $\frac{1}{16}$ " single." This resembles a dihybrid ratio, but not the ordinary sort. "Walnut" is a new phenotype. It was found that when the " singles " obtained were inbred, they produced "singles." This indicated that "single" depends on the interaction of the recessives of " rose " and " pea." The $\frac{9}{16}$ group of phenotypes obtained in an ordinary dihybrid ratio contain at least one factor for each of the dominant allelomorphic pairs. Hence we may assume that " walnut " in this case is effected when a phenotype possesses at least one factor for " rose " *and* one for " pea." Fig. 363 depicts the above explanation. " Walnut " appears to express a reaction between *two* distinct dominant characters. " Single " occurs when the genetic constitution is a double recessive, *i.e.*, " rrpp."



F_1 ♀ Gametes

F_1 ♂ Gametes

F_2	RP	Rp	rP	rp
RP	RRPP Walnut	RRPp Walnut	RrPP Walnut	RrPp Walnut
Rp	RRPp Walnut	RRpp Rose	RrPp Walnut	Rrpp Rose
rP	RrPP Walnut	RrPp Walnut	rrPP Pea	rrPp Pea
rp	RrPp Walnut	Rrpp Rose	rrPp Pea	rrpp Single

$\frac{9}{16}$ Walnut : $\frac{3}{16}$ Rose : $\frac{3}{16}$ Pea : $\frac{1}{16}$ Single

FIG. 363. — Modification of Dominant Factors in combination — shown here by inbreeding Rose-comb and Pea-comb fowls.

Complementary Factors. As new types of experiments were performed, new complications appeared and new explanations were devised to bring them in line with orthodox Mendelian hypothesis. One of these resembles the last case but differs in that no *new* character appears as the result of the interaction of factors. When purple sweet peas are crossed with white sweet peas, the result is *usually* $\frac{3}{4}$ purple (P) and $\frac{1}{4}$ white (p), and when white is crossed with white, the result is usually white. Bateson and Punnett found at times that white × white gave purple.

When the latter were crossed, they gave $\frac{9}{16}$ purple and $\frac{7}{16}$ white. This can be explained as follows: The proportions suggest a dihybrid ratio and that two allelomorphs are present. Moreover, purple may be due to two *complementary factors*, one for purple and the other for color — possibly a *potential* purple *pigment* activated by a color *enzyme*. We can postulate *two* allelomorphs then, one pair being *purple pigment* (P) and its alternate, absence of pigment (p); the other pair being *color activator* (C) and its absence (c). It would follow that both P and C would have to be in the same zygote to get a purple flower. Suppose we treat these allelomorphs as we did in the dihybrid ratio in peas. The following diagram indicates our hypothesis. In the lower part of each square is indicated the hypothetical color of the flower.

		Female Gametes			
		CP	Cp	cP	cp
Male Gametes	CP	CP CP Purple	Cp CP Purple	cP CP Purple	cp CP Purple
	Cp	CP Cp Purple	Cp Cp White	cP Cp Purple	cp Cp White
	cP	CP cP Purple	Cp cP Purple	cP cP White	cp cP White
	cp	CP cp Purple	Cp cp White	cP cP White	cp cp White

Zygotes are $\frac{9}{16}$ Purple and $\frac{7}{16}$ White.

Nine of these zygotes ($\frac{9}{16}$) contain at least one factor for color and one factor for purple pigment; the other seven contain (1) neither, (2) or only one or the other, (3) or possibly two of the same positive factor, (4) but not *both* C and P. We can understand now why the interbreeding of certain whites would produce purple. Inheritance similar to this occurs in a number of other cases and the above explanation fits there as well. The complementary factor hypothesis throws light on the reappearance, after many generations, of characters that have been latent. These are known as reversions.

Lethal Factors. Sometimes offspring possess characters that cause early death. These are known as *lethal* factors. Apparently these must be present in a double dose in the zygote to be effective, *i.e.*, to be lethal. In other words, the zygote must be homozygous in respect to this factor; if it is heterozygous, the lethal factor is not effective. However, it may be conceived that if *both* parents are each heterozygous with regard to this factor, then there is a possibility of *some* offspring being homozygous in respect to it and so destined to an early death.

Sex Determination. What are the factors which determine the sex of an individual? This question has long interested many inquiring minds. Many untenable theories have been advanced. It remained for the Mendelian and cytologist to make substantial contributions to the solution of this age-long mystery. It occurred to many experimenters that sex is inherited in the Mendelian fashion. Let us assume that the case is similar to that in which hybrid tall-dwarf peas were crossed with pure dwarfs, *i.e.*, Tt × tt and where the result was 50% *heterozygous* dominant and 50% *homozygous* recessive. In sex inheritance, the offspring are about 50% male and 50% female. Furthermore, the male appears to be heterozygous and the female homozygous in this type of inheritance. In that case the male would produce two kinds of gametes and the female but one type of gamete. Cytological studies of gonad cells, of spermatogenesis, oogenesis and of germ cells reveal chromosomal conditions which confirm the above assumptions and together with Mendelian experiments permit the construction of a theory of sex determination more satisfactory than any hitherto advanced.

About twenty-five years ago examination of the gametes of certain insects indicated two kinds of sperm. One had an *extra* chromosome which was lacking in the other type of sperm. All the eggs had the extra chromosome. Moreover, the primitive germ cells and body cells of the female had *two* of these "*accessory*" chromosomes in addition to a certain number of other chromosomes, now called "*autosomes*." The cells of the male body and its primitive germ cells also had the same number of *autosomes* and but *one accessory* chromosome. McClung, in 1902, suggested the relation between sex determination and these accessory chromosomes, now called *sex chromosomes*. Extensive work on many forms, principally insects, revealed the same general condition. The evidence from chromosomes supports the theory that sex is determined *at the time of fertilization* by the egg combining with a *male-determining* or a *female-determining* sperm, and that so far as we know the type of sperm involved depends on chance.

Let us represent the cells of the female body by the formula " AAXX " (Fig. 364), that is, they are homozygous. All female gametes would be represented by the formula " AX." The male body cells would be represented by the formula " AAXO " and there would be two types of gametes, namely, " AX " and " AO." If a zygote is formed from an egg " AX " and a sperm " AX," then all the developing body cells would be " AAXX," which is exactly the formula of the female body cells. However, if an egg, " AX," united in fertilization with the other type of sperm, " AO," the zygote and all developing cells would have the formula " AAXO," which is the formula *found* in male body cells. Therefore the facts support the theory.

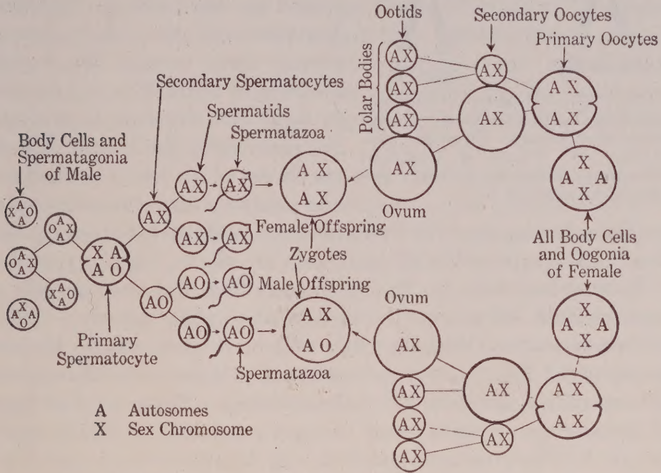

Ootids
Secondary Oocytes
Primary Oocytes
Polar Bodies
Secondary Spermatocytes
Spermatids
Spermatazoa
Body Cells and Spermatagonia of Male
Female Offspring
Zygotes
Male Offspring
Ovum
All Body Cells and Oogonia of Female
Primary Spermatocyte
Spermatazoa
AX
AO
A X A O
A X A X
A X A O
A Autosomes
X Sex Chromosome

FIG. 364. — Relation of Sex Determination to Oögenesis, Spermatogenesis and Sex chromosomes. (*a*) All eggs are alike as to sex chromosomes; (*b*) two types of sperm as to sex chromosome; (*c*) equal numbers of male and female offspring.

In some cases, the sex chromosome or " X " chromosome has a mate, called the " Y " chromosome, which is supposed to carry but a few or *no* unit characters. The " Y " chromosome is of *different* *shape* and usually pairs with the " X " chromosome in synapsis. The " Y " chromosome of Drosophila (Fig. 365) is larger than its companion, the " X " chromosome, and is of different form. A series of forms of animals has been found in which the " Y " chromosome is smaller than the " X " chromosome, and forms are found in which there is no mate and where the condition in the body cells of males may be represented by the formula " AAXO." Variations in the "X" chromosomes also occur. In certain moths and butterflies and possibly in birds the situation is reversed. In these cases, the female is heterozygous as to sex chromosomes and produces two types of gametes, (*a*) those having the "AY" chromosome outfit and (*b*) those having the "AX" type, while all the sperm are of the "AX" type.

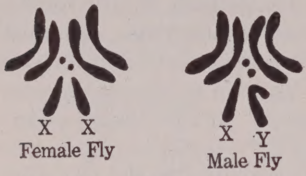


FIG. 365. — Diagram of chromosomes of male and female Drosophila (after Bridges). (From Morgan, *Critique of Theory of Evolution.* Princeton University Press. Reprinted by permission.)

Painter has come to the conclusion that the somatic cells of men contain 46 autosomes and another pair, namely, " XY " chromosomes, and that the body cells of women contain 46 autosomes and " XX " pair of chromosomes. Human ova thus possess 23 autosomes plus one " X " chromosome. There are two types of human sperm which occur in equal numbers: (1) 23 autosomes + one " Y " chromosome and (2) the 23 autosomes + one " X " chromosome. The student can readily see that fertilization of an egg by the first type of sperm would produce the chromosome equipment which body cells of males possess, while fertilization by the other type of sperm would produce the chromosome equipment shown by female body cells. A peculiar case is that of the honey bee. The somatic cells of the queen bee have 32 chromosomes and her egg cells 16. In our account of the honeybee we found that drones develop from unfertilized eggs. Theoretically, the body cells of drones should have 16 chromosomes, which is the case. There is no regular reducing division in sperm-cell formation in the drone, so that its sperm cells have 16 chromosomes. The drone mates with a queen, and thus, in case of fertilization, an egg with 16 chromosomes unites with a sperm having 16 chromosomes and produces a zygote with 32 chromosomes, which is the body cell number of the queen.

Modification of Sex. Recent work by Riddle and others indicates that although sex may be *determined* as outlined above at the time of fertilization, yet this is merely a tendency which may be later modified by physiological conditions. For example, the female of a certain variety of pigeon lays two eggs at a time, one of which usually develops after fertilization into a female and the other into a male. The eggs differ in appearance. The *female* egg is larger, has more nutriment and the rate of metabolism is lower than in the *male* egg. If eggs are removed from the pigeon as soon as they are laid, the pigeon lays oftener than normally. It is found after a time that both of these *later* eggs develop into females. Riddle suggests that excessive egg laying changes the metabolic rate of the *male* egg to the level of the *female* egg so that both develop into females.

When twins in cattle are of the same sex, they are normal. At times, however, calves appear of which one is a normal male while the other, called a *free-martin*, resembles a female in some respects but is otherwise a male. F. R. Lillie, after investigation of many specimens obtained at different stages of development, noted different embryological modifications and decided that the free-martin began life as a female. However, the sex organs of its male companion developed earlier, and the foetal testes of the male twin secreted the hormone which normally causes the development of the secondary sex organs. In this peculiar instance, the male hormone circulates in the blood system common to *both* twin foetuses and not only interferes with the development of some female secondary sex structures of the female calf, but also brings about, in the female, the development of certain structures of the male sex.

The effect of the loss of female hormones is evidenced by the much-quoted experiment of Goodale. He removed the ovary from a female Rouen duck. It gradually developed the distinctive male plumage. Similar effects are noted in other forms in which the sexes differ in appearance. An extreme case has been described by Dr. F. A. Crew of Edinburgh. A hen of a pedigreed stock (Fig. 344) had been known to lay eggs from which chicks had been hatched. She stopped laying and developed certain secondary male sex characters. Her behavior became that of a male. This metamorphosed female mated with another female and fertilized the eggs of the latter and from them chicks developed. In this case the change not only affected the secondary sex characters but *also the gonads.* Examination after death indicated that the ovaries had degenerated and testes had developed in place of them.

Forms intermediate between male and female and called intersexes have been found in a number of cases. Goldschmidt found them in crosses between different varieties of moths. In the past, differences rather than resemblances between the sexes in the human species have been overemphasized. The popular conception is probably greatly influenced by literary ideas rather than scientific observations. Social customs served to further accentuate the differences. But after all the body possesses not only organs of reproduction but also those of metabolism and adjustment and these are very similar in both sexes.

Linkage. The principle of the independent assortment of factors when two or more pairs of characters were inbred has been stated to be a corollary of Mendel's law of *segregation.* It has been tested in experiments with various plants and animals with positive results. But many *other* experiments have indicated an association or *linkage* of characters in heredity. T. H. Morgan is largely responsible for the development of this principle, now regarded as one of the fundamental laws of heredity.

It has been evidenced in experiments with insects, cats, rats, rabbits, fowls, man, peas, corn, beans, cotton, tomatoes and many other forms. Morgan suggested that linkage of factors in heredity was due to their genes being present in the same chromosome. If, in germ-cell formation, such a chromosome is delivered intact to a gamete, then the characters developed from such linked genes would appear associated in the offspring. Examples of linkage are: (1) In the sweet pea, purple flowers with long pollen grains; (2) primrose, short style with magenta corolla; (3) garden pea, late flowering with colored flowers; (4) tomato, green foliage with two-celled fruit; (5) beans, seed pattern with vine habit; (6) rat, albinism with red eye.

As a result of long-continued breeding experiments with the little fruit fly, Drosophila, Morgan came to the conclusion that — "In Drosophila it has been demonstrated . . . that there are exactly as many groups of characters that are inherited together, as there are pairs of chromosomes." The Morgan "Fly Squad" found four groups of such characters. The members of any one group are inherited together. The members of any one group appear to be inherited independently of the members of any other group. There are four pairs of chromosomes. There are three large groups of characters and three pairs of large chromosomes; there is one small group of characters and one pair of small chromosomes. The distribution of linked characters in successive generations agrees with the chromosome distribution. The Drosophila investigators have made a map (Fig. 366) of many of the genes showing that each has a definite location on a particular chromosome. The genes are arranged in a linear fashion along the chromosomes as the linkage theory would indicate. However the position of a gene bears no relation to the location of that character in the adult.

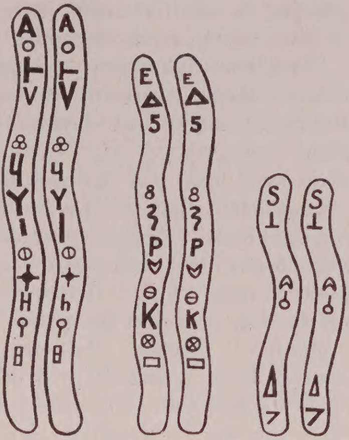


Fig. 366. — Diagram illustrating the theory of arrangement and distribution of genes (factors) in chromosomes. This imaginary animal has three pairs of chromosomes. According to the diagram, homozygous characters are represented by equal-sized figures within the chromosomes; while heterozygous characters are represented by unequal-sized figures. The larger figure in that case represents the dominant condition.

Crossing Over. In some cases the usual association of characters in heredity is departed from. New combinations appear. The hypothesis called *crossing over*, attempts to explain this. Cytological examination of germ cell formation in such cases reveals that in synapsis the chromosomes appear (Fig. 367) twisted around each other and so when they part company in the reduction division, the twisted chromosomes might *break* at the crossing points, and thus a new alignment of chromosome pieces *may be* effected. This aids in ex-

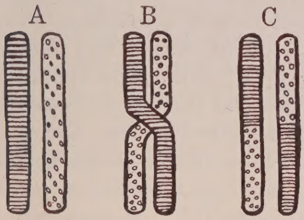


Fig. 367. — Crossing Over Hypothesis. When germ cells are formed homologous chromosomes come together in synapsis as in A.; At times they bend around one another as in B.; When they separate, in that case, they may have a new alignment of genes, as shown in C.

plaining the origin of many cases of new combinations or groups of characters in certain hybrids.

Sex-Linked Inheritance. Many cases have been found which indicate linkage between sex and some other character. One of the first examples was observed by Morgan. Drosophila is normally red-eyed. A white-eyed form appeared. When such a white-eyed male was mated with a red-eyed female, the results were different than when a white-eyed female was mated with a red-eyed male. Plumage peculiarities in fowls are associated with sex. Many other examples are known. Two interesting examples occur in man. First: Hemophilia or the tendency for the blood *not* to clot, possessed by certain individuals popularly known as "bleeders." Second: Daltonism, a kind of color blindness which appears to be associated with inheritance of sex. We will consider this in detail. The sons of a color-blind man are never color-blind nor are his daughters, but some of the sons of the latter are color-blind. Color-blindness seems to cross from one sex to the other from generation to generation. A color-blind female produces color-blind offspring oftener than a color-blind male. There are fewer color-blind females than males. A normal-eyed male never has color-blind descendants, but a normal-eyed female may have color-blind descendants.

These facts suggest that the factor for color-blindness is associated with the factor for sex. Therefore the two are carried by the same chromosome, namely, the "X" chromosome, although this does not imply that the "X" chromosome *always* carries the factor for color-blindness. Since man has but one "X" chromosome, the factor for color-blindness when present is associated with this chromosome and not the "Y" chromosome. The factor for color-blindness is not carried by the "Y" chromosome because color-blindness is transmitted by females, and these do not possess the "Y" chromosome. When a normal-eyed female produces some color-blind descendants, this indicates that although she is homozygous for sex she is heterozygous for color-blindness; that is, this factor is carried on one of the two "X" chromosomes. Finally, in order to be color-blind herself, she must have this factor linked with both her "X" chromosomes. A theoretical formula of the various conditions is presented diagrammed below. Let "X" represent a normal sex or accessory chromosome, and "x" when this chromosome carries the factors for both sex and color-blindness. We will omit the autosomes since they appear to have nothing to do with the matter. "XY" represent the sex chromosomes of a normal-eyed man and "xY" those of a color-blind man. "XX" would be the sex chromosomes of a normal-eyed woman who has no genes for color-blindness linked with the sex chromosomes.

Let us consider a few possible marriages.

First. A normal woman marries a color-blind man.

P_1 ♀ X X x Y ♂
Gametes ♀ X X
♂ x Y
F_1 2 Xx 2 XY

None of the children is color-blind. The sons are genetically normal. Marriages with normal women never produce color-blind offspring. *These* daughters, however, though homozygous for sex are heterozygous as to color-blindness. Half their eggs will be normal and half will carry color-blindness.

Second. Let us see what would happen and what does happen when one of these "Xx" women marries a normal man.

P_1 ♀ X x X Y ♂
Gametes ♀ X x
♂ X Y
F_1 XX + Xx + XY + xY

Half the daughters are genetically normal as to color-blindness and this is true of half of the sons. Half of the sons are color-blind. They inherited this through a normal-eyed but genetically impure mother from a color-blind grandfather. Half the daughters of the present marriage carry color-blindness on one sex chromosome and will behave in inheritance just like their mother.

Third. Suppose one of these normal-eyed but genetically heterozygous women "Xx" married a color-blind man "xY."

P_1 ♀ X x x Y ♂
Gametes ♀ X x
♂ x Y
F_1 Xx + xx + XY + xY

Half the daughters are like the mother, *i.e.*, "Xx," and though normal-eyed, yet are heterozygous as to the character color-blindness. The other daughters "xx" are homozygous as to color-blindness, *i.e., they are color-blind.* Half the sons are normal and half are color-blind. This type of mating would rarely occur, but when it does, some color-blind daughters appear.

Fourth. Suppose one of the color-blind women married a normal man.

P$_1$	♀ x x			X Y ♂
Gametes	♀	x	x	
	♂	X	Y	
F$_1$		2 xX	2 xY	

All the sons are color-blind and all the daughters carry color-blindness though functionally normal-eyed. All of these daughters marrying normal men will have some color-blind sons. The theoretical possibilities of inheritance from different kinds of matings, based on the assumption that the factor for color-blindness is linked with that for sex and therefore charted as shown in the above diagrams, are realized in human marriages of the types postulated. The conclusion is that the hypothesis is reasonable.

Hemophilia is more common among men than women. If by chance a woman should be homozygous as to this factor, she would be hemophilic and it *would tend to be lethal at puberty.*

Theory of the Gene. It is true that no one has seen a gene. But the existence of such bodies is considered more than hypothetical. Professor Morgan and his cooperative group consider that the chromosomes of Drosophila contain about 5000 genes. Theoretical evidence of genes has been presented in the preceding pages. The dual nature of somatic chromosomes and the haploid nature of gametic chromosomes, together with the operation of the laws of unit characters, of segregation, of dominance, of independent assortment, of linkage and of the sex chromosomes, all support the theory of the gene. No other interpretation seems possible. The conception of the gene is being extended. For example, attention has been called to a case in which two pairs of allelomorphic genes interact to produce purple color in the sweet pea. Morgan believes that at least twenty-five pairs of genes are responsible for eye color in Drosophila. On the other hand, in some cases it appears that one pair of genes affects more than one character. Finally it appears that the environmental conditions must be of a certain sort in order that the potentiality of the genes be realized in development.

Many of the results of research in genetics throw light on the problem of the generation of species and will be discussed in the chapter on evolution.

Practical Applications of Genetic Principles. It would appear that the discovery of the laws of inheritance, as elucidated by the geneticist, would prove to be of great value to the practical breeder of plants and animals. In spite of a quarter of a century of contributions in pure genetics, however, the practical applications have so far been rather disappointing. There are a number of outstanding exceptions.

For example, Biffen in England combined in one variety of wheat a number of valuable characters appearing in a number of wheats. Shull appropriately calls the result a "*synthetic wheat*" produced as a result of the application of Mendelian principles. Biffen combined the gluten quality, on which good bread making depends; resistance to rust; resistance to mildew; early ripening and resistance to drouth.

It appears that characters in plants are more simple and can be sorted out successfully by the Mendelian method. Only too often, in animals useful to man, the characters desired by the breeder are found to be too complex for this kind of analysis. The breeder follows about the same rule as his predecessors — namely, selection. If he desires to develop a good herd of milk-producing cattle, he uses mothers which have made a high record in milk production. Scientific investigation has shown, however, that the type of male used is also of great importance. The same importance seems to be true in the case of selecting both males and females to secure high egg production. Animal breeders consider the pedigree of the herd of great value because whatever improvement has been achieved is represented somehow in the pedigree.

A few successes are noted here. Immunity to disease appears to be a Mendelian factor in many varieties of plants and so can be incorporated with other useful characters. In corn, resistance to smut and to rust has been discovered. The vigor of certain corn hybrids is greater than that of either parent. This has also been found in the case of other useful plants and in some of our domestic animals. In fact all sorts of domestic varieties of plants and animals are being subjected to the Mendelian type of analysis with some degree of success. The indications are that these investigations carried out in scientific fashion will bear more fruit in the future, and that much greater progress will be made in this way than by the slower methods of the older selectionists. The advantage of the newer method of approach will be that the phenomena will be better understood and the results more secure. Knowledge of the processes of nature will increase our control.

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CHAPTER XXV

DISTRIBUTION OF ORGANISMS IN TIME AND SPACE

PART I. PALAEONTOLOGY

Introduction. Palaeontology is that portion of biological science that deals with organisms which once lived on the earth and are now found buried in it as *fossils.* A fossil is the rock-like remains of a former living organism. The word literally means something that is "dug up." Fossils are usually petrified teeth, bones, shells or wood. Soft parts, such as muscles and viscera, usually disintegrated too soon to become permanently recorded as fossils. Not all localities are favorable for such preservation. Pressure, elevation, foldings and erosion destroy fossils. Often they are discovered when a cut is made through a hill for a railroad or when uncovered by erosion. At rare intervals extensive deposits of fossils are discovered. It is, after all, remarkable that enough material has been recovered to make possible the science of Palaeontology, when one considers the very many conditions operating against the preservation and discovery of such specimens.

History of Palaeontology. Fossils were not unknown to the ancients. Aristotle thought they were examples of spontaneous generation taking place in the depths of the earth, and that such forms never had a chance to live on the surface. When hippopotamus bones were found in Sicily, Empedocles (450 B.C.) thought they indicated a great battle in ancient times between giants and Gods. Xenophanes of Colophon (500 B.C.) found fossil fish in rocks near ancient Syracuse and thought they had been caught in the rocks when these were under water. Nearly two thousand years later Leonardo da Vinci, a man of unusual common sense (or rather uncommon sense), urged that fossils were the remains of former living animals. In fact, Steno, professor of anatomy at Padua in 1669, compared the teeth of living sharks with similar fossil structures and asserted that they were identical. During the eighteenth century it was commonly believed that fossils were remains of animals that died in the great flood of Noah's time. For example, one specimen appeared to be the fossil skeleton of a child. This afterwards proved to be a large salamander.

It is said that Werner (1750–1817) first suggested that the relative age of different rock strata could be identified by their fossils. This method is employed today and is known as the "*Fossil Index*." Werner also noted that fossils more nearly like existing living species occurred in more recent strata. Cuvier (Fig. 368), the distinguished comparative anatomist of France, studied fossils of Vertebrates unearthed near Paris. He asserted that they ought to be listed with living animals. He would not acknowledge that any living forms were descended from such ancestors and in attempting to account for their distribution claimed that there had been eight great successive catastrophes like the flood in Noah's time. Lamarck studied Invertebrates, showing, for example, that some fossil Mollusks were similar to living forms and that some had long ago become extinct. This had a distant bearing on the theory of evolution which he developed. William Smith (1769–1839), an English surveyor, suggested that there had been a regular succession of layers of rock or strata.

FIG. 368. — Georges Cuvier.

In 1830, Charles Lyell (Fig. 369), an English geologist, published an epoch-making book in which he presented a new (and what is still held to be true) explanation of the history of the earth. He held that forces present today operated likewise in the past and that these forces not only brought about the changes in the earth's crust in the past but are doing so today; that it is a continuous process. Streams cut down continents, and transport material to new places. Changes in temperature, wind, waves, volcanoes and glaciers have long been at work. Animals died all along the line of time; they were later buried. This process took thousands upon thousands of years and in this period there was a succession of animal forms.

Estimating the Age of the Sedimentary Rocks. The history of the earth, back to remote times, is outlined in the stratified rocks, those on the surface being the newest and those at the bottom the oldest. Due to such agencies as earthquakes, the regularity of stratification is in many cases upset. The geologist has methods by which he *estimates* the total age of the entire strata of sedimentary rocks. This is done in three ways:

First. Estimating the age of the ocean. Considering the present salt concentration of seawater, the rate at which it is increasing, and assuming a "fresh-water" ocean to begin with, the conclusion is that oceans are about 100 million years old.

Second. Rate of sedimentation. Fossils are found only in the sedimentary rocks, the total thickness of which amounts to 75 miles. At the present rate of sedimentation, about 3000 million years would have been required to form these rocks.

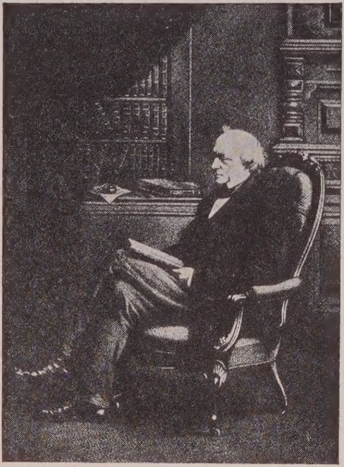

Fig. 369. — Charles Lyell, Geologist.

Third. Radioactivity. The rate at which radio-active uranium breaks down into helium and further into lead is determined. It is possible then to compute the length of time during which this disintegration has taken place and from this the age of the rocks in which these radio-active substances occur. Applying this method the conclusion is that some rocks are over 1000 million years old.

The geologist divides the portion of the earth's history with which he is concerned into great *Eras*, each of which is variously divided into *Periods*. He estimates a total length of time and then apportions a certain percentage of this to each era and period, determined by the thickness of the strata and other factors. The student can see that geologic time has not the precise character of time in human history. The periods are often named after localities where rich deposits of certain types of fossils have been found. The Cambrian Period, for example, is named after Cambria, the old Roman (Latin) name for Wales. *Fossils are found in the sedimentary rocks.*

Eras of Geologic Time. We will not discuss here the *early* formation of the planet, earth, since these questions belong to another field which might be called astronomical geology. Undoubtedly long ages were occupied in the work of sedimentation, during which many geologists recognize five *Eras*, first an older *Archeozoic* and later *Proterozoic*, these two comprising about 55% of geologic time, *according to Professor Schuchert*, who assumes that these ancient *Eras* existed for 275 million years. Geologists often combine both periods into the *Precambrian.* Following the Precambrian and extending down to the present, a period of 225 million years, are *three great Life Eras. Most of the fossils which give distinct evidence of plant and animal structure come from these strata. It is evident that the Life Eras comprise less than half of the estimated age of the sedimentary rocks.* Professor Schuchert truly says: " Any one wishing to be impressed with the immensity of *Geologic Time* should stand on the brink of the Grand Canyon in Arizona and reflect on how long it has taken the Colorado River to cut this nearly mile-deep gorge, the most beautiful and impressive in the world. He should also think of how long it has taken the seas to lay down this depth of *Paleozoic Strata* and the more than two miles of *Proterozoic* sediments beneath them. Having done all this, he should remind himself that after all, he has seen but a small part of the whole geologic column." The present tendency as noted above, is to increase Professor Schuchert's estimate of geologic time.

The *Life Eras* are first the ancient *Paleozoic*, followed by the *Mesozoic* and later by the *Cenozoic.* Each *Era* is subdivided into *Periods* characterized by fossils indicating the plant and animal life and presenting evidences of oceanic and continental changes as well as modifications in climate.

Geologic Time Table. The following table indicates how the geologist divides the great *Life Eras.*

GEOLOGIC TIME TABLE

ERA	DURATION MILLIONS OF YEARS 500–1000 (Estimate)	PERIODS	CHARACTERISTIC LIFE FORMS
CENOZOIC	Three to five per cent	Quaternary Recent or Post-glacial Pleistocene or Glacial Tertiary Pliocene Miocene Oligocene Eocene (dawn)	Age of Man-Intelligence. Age of Mammals and Seed Plants: Birds and Fishes like present-day types: There was a great evolution of Mammals. The gigantic Reptiles of the preceding age are gone, leaving types like present-day Reptiles. Vast migrations during latter part of this Era. Then came glacial periods also.
MESOZOIC	Five to ten per cent	Cretaceous (Upper) Comanchian (Lower Cretaceous) Jurassic Triassic	The great age of Reptiles, Dinosaurs; Pterodactyls, Ichthyosaurs. First Birds (toothed) and Reptile-mammals. Plants, Marine Invertebrates and Insects attain modern condition. Modern bony Fishes have arrived.
PALEOZOIC	Fifteen to twenty-five per cent	Carboniferous *a.* Permian *b.* Pennsylvanian *c.* Mississippian Devonian Silurian Ordovician Cambrian	Amphibians the dominant land Vertebrates; Great Coal Age. Swamps and dominance of Pteridophyte Plants and Pteridosperms. First Insects and Reptiles. Armored (archaic) Fish abundant. Great invertebrate evolution. Many of these forms not persisting.
PROTEROZOIC	?	Traces of fossils	These two Eras sometimes called the Precambrian.
ARCHEOZOIC	?-many-?	No fossils found	

The following summary is a brief commentary on the changes which took place as period succeeded period.

Precambrian. In the Proterozoic, calcareous Algae and even traces of Annelids have been found.

Paleozoic Era. *Cambrian.* All the phyla of invertebrate animals are represented but not necessarily by present-day forms. Crab-like animals called Trilobites, and Brachiopods, mollusk-like forms but with a dorsal and ventral shell, occur in great numbers. Gasteropods and Cephalopods began to increase.

Ordovician. The seas swarmed with a great variety of Invertebrates. There were reef-building corals and indications that fresh-water fishes had appeared.

Silurian. Great wealth of Invertebrates. Land plants appeared and also scorpions and some fresh-water fishes. The climate was warm and moist but large areas gradually become arid.

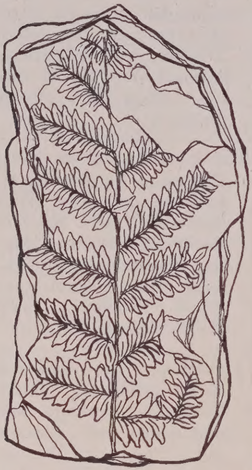

Fig. 370. — Fossil fern from carbonaceous shale.

Devonian. More green plants covered the land, the dominant Invertebrates decreased and fishes came into the ascendancy. Many sharks and large-headed lung fishes. There were large fern-like plants, lycopods. No insects as yet. The Amphibia emerged. The fresh waters contained many fishes.

Mississippian. The leading Invertebrates receded from their erstwhile dominant position. Great marine sharks, feeding on shelled forms, may have been responsible for this. Plant life advancing.

Pennsylvanian. The climate was warm and pleasant with abundant rains. Oceanic and continental changes formed great swamps. A wealth of spore-bearing plants and the spores scattered by rain and wind. There were ferns (Fig. 370), giant lycopods and horsetails and seed-bearing ferns, the like of which no longer exist, the so-called Pteridosperms; Cycads appeared and conifer-like forms but no modern Conifers or flowering plants. There were many air-breathing land animals, snails, insects, Amphibia and some evidences of reptilian life. Toward the close of this period the great forests of spore-bearing plants vanished to form the coal beds. There were many cockroaches, dragon flies, scorpions and spider-like forms. Gradually the climate became drier and colder, causing modifications in the plant and animal life. There were repeated mountain formations.

The seas contained many Invertebrates. The first land Vertebrates to appear were the Amphibia, the " leading " land Vertebrates from the late Devonian on into the Pennsylvanian. These Amphibians are called Stegocephalia (Armored head). Some of them were ten feet in length and they lived in and out of the water.

Permian. During this period, smaller forms of insects appeared in place of the larger ancient types. Metamorphosis was introduced as an adaptation to a dry climate. Many small types of reptiles appeared and Cycads, more adapted to a colder climate.

Mesozoic Era. This has been called the *Age of Reptiles.* They dominated as do now the Birds and Mammals. Giant herbivorous and carnivorous forms there were. Some types became adapted to marine life and others developed mechanisms for flight. Early in the *Triassic* there arose small reptile-like, egg-laying Mammals. These gave rise later to the suckling Mammals. The Stegocephalians disappeared in the Triassic. The Invertebrates characteristic of the Paleozoic disappeared. The early Mesozoic was the great Cycad Age.

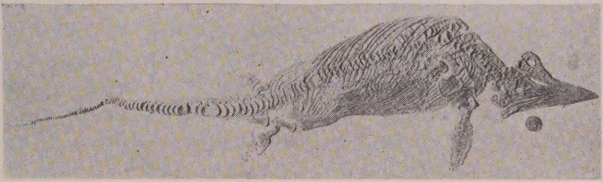

FIG. 371. — Ichthyosaur — Fish lizard. (From specimen at College of the City of New York. Photo by Stratford.)

Jurassic Period. Tree Ferns, Horse-tails, Lycopods, Cycads, Ginkos and Conifers formed the dominant vegetation, but the spore-bearing forms lost the ascendancy. Small frogs appeared and many types of reptiles. The Dinosaurs reached the maximum of their evolution and also marine reptiles, the Ichthyosaurs (Fig. 371) and aerial reptiles, called Pterodactyls. Archaeopteryx, the oldest bird ever found, was taken from the strata of the Jurassic.

Cretaceous. This period gets its name from chalk, which is characteristic of cretaceous deposits. These are made up of the calcareous skeletons of minute pelagic animals and plants prevalent in this period. Great ocean floods spread over the lands and there were marked changes in climate. Ichthyosaurs, Pterodactyls and Dinosaurs were on the decline. This is true of the Cycads also.

The last of the toothed birds, such as Hesperornis, appeared in the upper Cretaceous. During all this period the small, defenseless Mammals played a minor rôle. Flowering Plants were evident.

Cenozoic Era. This has been called the *Age of Mammals.* In the later *Eocene,* some Mammals (whales) became inhabitants of the sea. The little equine form, Eohippus, lived in this period. There were also toothless, flightless birds resembling the ostrich, but none of the ancient reptile types. The Mammals radiated out into the modern orders. Turtles, alligators and crocodiles attained their greatest development in the *Oligocene.* The climate was pleasant. In the *Miocene* the climate became cooler, mountain forming took place, and in some sections desert conditions prevailed. The *Miocene* has been called the Golden Age of Mammals. There were woody trees and shrubs resembling those of the present. Grasses (Monocotyledons) appeared and played their part in the evolution of herbivorous Mammals, such as horses.

In the *Pliocene,* elephant-like forms, the mastodons, evolved, 3-toed horses, llamas, giraffe-like camels, rhinoceroses, saber-toothed tigers, true cats, and in Asia, cattle, sheep and goats appeared. In South America that unique collection of ancient mammal types such as the tree sloths, ant-eaters, armadillos were left alone to develop. In the *Pleistocene,* the ground sloths appeared there. The true bears wandered over into North America from Asia. Africa was the scene of great activity in the evolution of its peculiar mammalian types which remain today, but are gradually being reduced by the onward march of human civilization.

Meaning of the Evidence. Invertebrates appeared long before Vertebrates, Fishes before Amphibia, Ferns before Flowering Plants, Reptiles before Birds and Mammals, etc, The lower strata contain generalized forms, the more superficial (later or younger) strata show more specialized forms. Many localities on the land have once been the floor of the sea. Corals are now found in fossil beds, hundreds of miles from the ocean. Tropical forms are found in localities that now have severe winters. North and South America were separated from Middle Eocene time to late Miocene. There are evidences of great migrations of animals in response to great climatic changes. Either the migration or the great environmental changes may have produced new species. Lull says: "The animals followed three great evolutionary lines, culminating in the Mollusks, the Arthropods and the Vertebrates;

of these the Cephalopods represent the final goal of molluscan evolution, the insects of arthropod evolution and the Mammals of vertebrate evolution."

Insect Evolution. The insects are supposed to have been derived from primitive Arthropods called *trilobites* (Fig. 184). They had amphibious habits, had a number of similar segments, and lived in the early Paleozoic Era. From this type also originated Crustacea and some of the Arachnida such as scorpions and the horseshoe crab, Limulus. The ancient insects were carnivorous and aquatic. During the late Permian and early Triassic there were few insects. Conditions had changed from a moist, warm climate to one cold and dry. Plant life was changing. Other types of animals responded to the change. Insects became more numerous in the lower Jurassic. The first Lepidoptera appeared in the middle Jurassic, and the first Hymenoptera in the upper Jurassic. These insects were plant eaters. In the Cretaceous appeared a wonderful development of Flowering Plants, and Lepidoptera and Hymenoptera associated with them. This proved to be of mutual advantage to both flower-visiting insects and the flowering plants and had a great deal to do with the rapid extension of these Spermatophytes. In the Tertiary, all the higher types of insects were well-established, social insects and parasitic forms as well. Lull says that the primary cause for the origin of insects from Trilobites was the great development of land flora and fauna in the Silurian and Devonian age of the Paleozoic Era. The profound change in climate in the Permian Period not only almost destroyed the Pteridophyte Flora, but introduced metamorphosis in insects by which they could survive inclemency of climate. The appearance of flowers in the Cretaceous is very important.

Life in the Carboniferous Periods. The Carboniferous division of the late Paleozoic comprises the Mississippian, Pennsylvanian and Permian Periods. During part of this period the climate was warm and moist. It was the great Coal Age during which the great Pteridophytes and Gymnosperms thrived. They were spore-bearing, rapid-growing and soft-wooded. These in turn were almost destroyed by the icy Permian climate. During the Mississippian, gigantic sharks were the dominant animals of the sea but not in the later periods.

Reptilian Evolution. The *Reptiles* probably originated from stegocephalian-like forms in the upper Carboniferous. The Permian furnished specimens of five out of the fifteen orders of Reptiles recognized by some authorities. From a short-legged, crawling, generalized type there developed cursorial, arboreal, aerial, fossorial, amphibious, aquatic and ambulatory types. This is an illustration of adaptive radiation. It also appears in the development of insects and was first clearly pointed out in the case of Mammals by Osborn. The Mesozoic has been called the Age of Reptiles, and America was the scene of their greatest developmental activity. Some were like modern crocodiles and turtles. There were great fish-lizards or Ichthyosaurs in an ocean which had no whales. There were also flying reptiles or Pterodactyls in the air which had no modern types of birds.

Dinosaurs. Certain reptiles called *Dinosaurs* were the dominant land Vertebrates from the middle Triassic to the close of the Cretaceous. They ranged in size from about that of a cat to forms vastly larger than the elephant. The bodies of many were short and stocky, their legs were long and unlike modern quadruped reptiles, these walked or ran on their hind legs, the tail acting as a balancing organ as in the kangaroo. The early forms were much like modern lizards. But from this type many diverse forms developed; some of great size; some carnivorous, some herbivorous; some protected with a bony armor; some quadrupeds, and some bipeds.

Tyrannosaurus (Fig. 372). The "Tyrant Saurian" (Osborn) represents the extreme development of carnivorous Dinosaurs. It was forty-seven feet long. The head was over four feet long, its great jaws had teeth from three to six inches long, and the toes were armed with sharp curved claws, six or eight inches in length. The head was twenty feet above ground when the animal stood up. The bend of the knee was six feet above the ground. Its forelimbs were small and it moved about on its hind limbs, and was *digitigrade,* like an ostrich. Its movements were slow and ponderous, hard to start, and difficult to stop. Its brain was small. It was one of the largest carnivorous animals that ever lived.

Brontosaurus, called the "Thunder Saurian" by Professor Marsh, was a great amphibious Dinosaur. Its skeleton was discovered near Medicine Bow, Wyoming, in 1898. A specimen sixty-six feet, eight inches long, was placed on exhibition at the American Museum of Natural History in New York, in 1905. Its estimated weight was 38 tons. It had a long, thick tail, a long neck, a short body and solid, heavy, pillar-like limbs. Its head was comparatively small. It probably ate soft plants and lived in shallow waters, rich in plant life, crawling out upon the land to lay eggs. Matthew appropriately names it, the "Leviathan of the Shallows."

The duck-billed Dinosaur, *Trachodon*, was over sixteen feet high when standing. It was herbivorous and the mouth was expanded into a broad duck-bill, covered with a horny sheath. The teeth totaled over 2000 in both jaws. The American Museum of Natural History in New York was fortunate in obtaining a rare specimen in which the skin has been preserved. The animal had apparently died a natural death and the soft parts, instead of decaying, were preserved for a time by desiccation in the hot sun, until petrifaction preserved it as a fossil mummy.

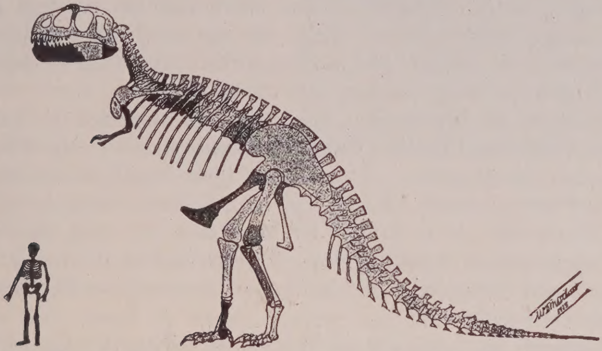

FIG. 372. — Tyrannosaurus rex. Compare with human skeleton at left. (American Museum of Natural History.)

During the Upper Cretaceous period and near the close of the Age of Reptiles, the climate of northern North America was similar to that prevailing now in Southern California. Plant fossils indicate the existence of fig trees, palms and the horsetail. With the close of the Mesozoic, the dominant position long maintained by the Dinosaur reptiles was lost. No trace of them appears in the Tertiary. They had thrived for millions of years. It is a great life cycle with its period of humble birth, its morning of youth, the noontime of its glory and its evening of death. Lull ascribes extinction to great elevation of land areas, the draining of great inland seas and the restriction of old haunts.

Evolution of Birds. Huxley has called Birds, "glorified reptiles," a simile justified by the results of embryological and anatomical comparisons. The origin of Birds from Reptiles is buried in obscurity. *Archaeopteryx* is the earliest known bird, found in the upper Jurassic and contemporary with early Dinosaurs. A description has already been given. It is not amiss here to recall the teeth in both jaws, the three-clawed fingers of the hand, and the long tail with a row of feathers on each side. *Hesperonis* was discovered in the Cretaceous of Kansas. It was about four and one half feet long. It could not fly, but had long powerful hind limbs and was probably an excellent diver and swimmer. It possessed teeth. *Ichthyornis* was much like our modern gulls and possessed the power of flight. It was smaller but had teeth. It was in most respects like modern birds. The birds of the next era, Cenozoic, were even more like modern birds.

Evolution of Mammals. Mammals are regarded as having arisen from small reptiles called *Cynodonts* found in the Triassic Period of the Mesozoic. The teeth of these Reptile-mammals are divided into incisors, canines and molars, as is characteristic of the Mammals. It is claimed by some that the early Mammals first appeared in South Africa. The increasing dryness of the climate and formation of dry land acted as stimuli to the development of a speedy form.

Mammals and birds were held in check during the Age of Reptiles. But they managed to survive and to assume a dominating position in the Cenozoic. They had developed a very important mechanism by which the body could maintain a constant temperature fairly well. This was later improved upon so that the maintenance of constant temperature enabled higher forms to exist, despite considerable changes in the temperature of the surrounding medium. The duck-bill and spiny anteater (Echidna) of Australia are considered survivors of early Reptile-mammals. These two forms are oviparous, but higher Mammals appeared and produced living young. Near the end of the Mesozoic pouched animals or Marsupials migrated in great numbers to Australia. Before any *higher* Mammals had developed, the Australian Region had become isolated from South America and the Marsupials were destined to continue for ages in a quiet environment in which there was little evolution.

Evolution of Horse. It is impossible in this brief review to study the palaeontological history of all forms of Mammals. The history of the horse is one of the most complete studies in this field. The wild horses found on our western plains were not immediately indigenous to America. They were *feral* (escaped from domestication) descendants of domestic horses brought to this country from Europe by early expeditions, such as those of the Spanish. In many of these expeditions the human members perished, but the horses roamed the wilderness, left offspring and so spread. A more ancient history of the horse has been painstakingly investigated. It has been traced back by a series of stages to the lower Eocene, early in the Cenozoic Era. The scene of great activity in its development was in America. (1) *Eohippus* (Fig. 373), found in the lower Eocene, was about a foot high. The forefoot had four toes and the hind foot had three toes and each had a vestige of an additional toe.

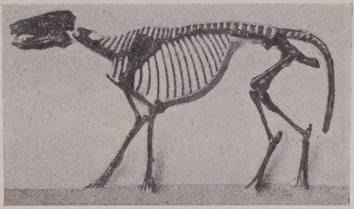
FIG. 373. — Eohippus, the little horse of the lower Eocene. (Am. Mus. Nat. Hist.)

The molar teeth had short crowns. The skull was small and the face and lower jaw were short. Fossil remains of these horses have been found in North America and Europe, but the latter disappeared toward the end of the Eocene. (2) *Mesohippus*, found in the Oligocene, was about eighteen inches tall. It has only three toes on each foot. The middle toe on each foot was longer than the others. It was similar in appearance to Eohippus, but the cusps on the teeth were united in ridges. It probably fed on juicy grass or leaves as Eohippus had done. (3) *Merychippus* was found in the Miocene and was about three feet high. All four feet had three toes as a rule, but the middle (third) was distinctly longer and the second and fourth well above the ground. The molar teeth had quite long crowns and the upper surface was worn down to a surface in which ridges of enamel alternated with dentine. The lower jaw was heavier. It crushed the green vegetation on which it fed. The face was longer.

There were many horses during the Miocene in western North America. The single middle toe was functioning more and more, while the toes lateral to it were becoming useless. This made possible swifter movements over the plains and was an important measure of defense. It is believed that North America and Asia were separated during part of the Tertiary but again united during the Pliocene.

(4) *Pliohippus.* This horse was about the same size as Merychippus. The two lateral toes had become further reduced. So Pliohippus was functionally a one-toed horse. The teeth had long crowns. (5) Equus, the fossil horse of the Pleistocene, was very much like the modern horse. It was five feet or more in height.

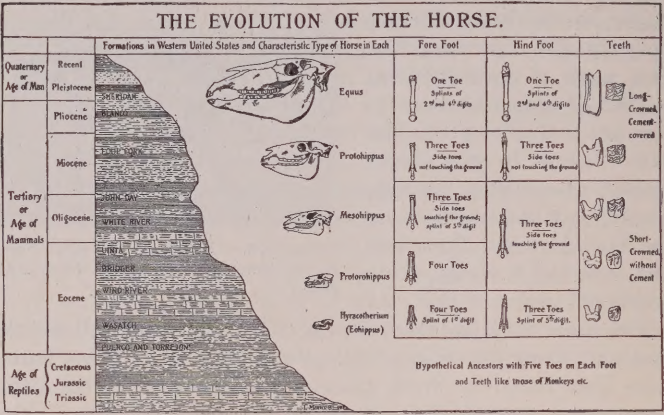
THE EVOLUTION OF THE HORSE.
Formations in Western United States and Characteristic Type of Horse in Each
Fore Foot
Hind Foot
Teeth
Quaternary or Age of Man
Recent
Pleistocene
Tertiary or Age of Mammals
Pliocene
Miocene
Oligocene.
Eocene
Age of Reptiles
Cretaceous
Jurassic
Triassic
SHERIDAN
BLANCO
LOUP FORK
JOHN DAY
WHITE RIVER
UINTA
BRIDGER
WIND RIVER
WASATCH
PUERCO AND TORREJON
Equus
Protohippus
Mesohippus
Protorohippus
Hyracotherium (Eohippus)
One Toe
Splints of 2nd and 4th digits
One Toe
Splints of 2nd and 4th digits
Three Toes
Side toes not touching the ground
Three Toes
Side toes not touching the ground
Three Toes
Side toes touching the ground; splint of 5th digit
Three Toes
Side toes touching the ground
Four Toes
Four Toes
Splint of 1st digit
Three Toes
Splint of 5th digit.
Long-Crowned, Cement-covered
Short-Crowned without Cement
Hypothetical Ancestors with Five Toes on Each Foot and Teeth like those of Monkeys etc.

FIG. 374. — Evolution of the Horse. From an exhibit in the American Museum of Natural History. (Courtesy A. M. N. H.)

There was but one toe on each foot. The animal ran on its toes. The upper surface of the long crowned teeth presented an admirable mechanism for grinding its characteristic food. The face and the lower jaw were long.

The horses of the Pleistocene were descendants of Pliohippus. Some made their way northwest via the land bridge across Behring Sea to Asia and Europe and others wandered into South America across the Isthmus of Panama. But all the American horses died out. When Eohippus lived in America, the climate was humid and this little animal lived on marshy ground. Later the climate changed. The air became dry, and hard plains were formed so that one-toed forms were better suited to these conditions. The succulent vegetation changed to dried grass, and the change in teeth and form of skull were adapted to this (Fig. 374).

Evolution of Camel. The history of the Camel shows that its ancestor, *Protylopus*, was about the size of a rabbit and lived in North America. The front feet had four distinct, useful toes. The first was not represented. The hind feet had two toes. This animal occurs in the late Eocene. From it sprang three lines of descendants. Two of these have disappeared. The third line lived in North America until late Pliocene or Pleistocene, when it migrated to South America and Asia and Africa. The Llama is a representative of the South American line. The Asiatic and African line is represented by the dromedary, or one-humped camel, and also the two-humped form. These have been domesticated for thousands of years. There are no other wild forms.

Evolution of Elephant. The evolution of the Elephant can be clearly traced from the late Eocene onwards. The fossil remains of a form named *Moeritherium* were found near Cairo, Egypt. This animal was probably about three and one half feet high. The Mastodons lived in the Pliocene and Pleistocene and were not in the same immediate line of ancestry as modern elephants. They ranged from Europe across Asia to Alaska and south through the United States but did not reach South America. They fed on twigs of evergreen trees. Remains have been found in swamps in several of the states, *i.e.*, New York, Indiana, Ohio. *Elephas primigenius* (Fig. 375), the hairy or woolly Mammoth, closely related to the living Asiatic elephant, was provided with long black hair and thick brown wool, enabling it to survive Arctic cold. It could withstand the rigors of an ice age. Frozen specimens have been taken from the ice in Siberia. One was discovered in 1799, and another in 1901. These animals were known to prehistoric man. Primitive artists made drawings of the Mammoth on the walls of caves. Mammoths flourished in the Pliocene and

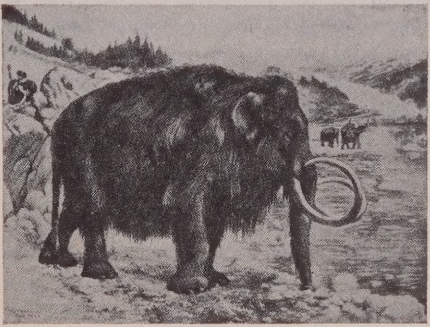

FIG. 375. — Elephas primigenius. After Osborn. From a painting by Charles Knight. (Courtesy Am. Mus. Nat. Hist.)

Pleistocene. They have been extinct for thousands of years. The only living representatives of the elephant group are the Indian and African species. *Elephas africanus* (Fig. 279), is larger, has enormous ears and longer tusks. Its ivory is more highly prized than that of the Indian elephant.

Appearance of Man. The Miocene was a period of great mammalian development. Climatic and earth changes took place in the Pliocene. Old land bridges disappeared and new ones were formed. Migrations of animals consequently took place so far as possible. Of all the forms, this was more possible in the case of Birds and Mammals. Man is thought to have appeared in this age. With the Pleistocene, during which the rise or elevation of the continents continued, the age of ice began. There were long periods of bitter cold alternating with short periods of warmer climate. Many kinds of animals were destroyed. Man was able to withstand the rigors of these long, terrible ages. The icy cold gradually receded further and further north and the Age of Reason and Intelligence and what is known as Human History finally began.

PART II. GEOGRAPHICAL DISTRIBUTION

Introduction. Living things occur everywhere — in the tropics; in arctic regions; on mountain summits; in valleys; in deserts; in ocean water; in brackish waters; in fresh waters; in caves; in rock crevices; in top soil; in the air. But fauna and flora are not evenly distributed. Africa has the gorilla, the chimpanzee and elephant, while Brazil, with conditions similar to those of Africa, has none of them but possesses the tapir, the sloth and New World monkeys. Why is not the tiger a native of America? Why are the Marsupials the prevailing Mammals of Australia?

According to the geographic distribution of animals, the earth's surface has been divided into zoogeographical regions, each characterized by an assemblage of forms peculiar to that region. Some of the forms are found in more than one region, but nevertheless the following distinct districts appear to be clearly indicated.

Zoological Regions. *A. Palaearctic Region.* This consists of Europe; Africa, north of the Sahara Desert; Asia, north of the Himalayas; Japan, etc.

B. Nearctic Region, consisting of North America and Greenland.

Let us discuss these two regions. Great groups of Mammals are represented here. Many forms found in both are closely related although differing in details. Examples of such similar forms are the bears, wild cats, foxes, hares and deer. Many trees are found common to both. They, of all the regions, are the most similar, and some students join them, forming the *Holarctic* region. It seems best to subdivide the Holarctic into the Palaearctic and Nearctic because of minor but distinct differences between the related forms occupying these regions of the earth. For example, the opossum, skunk, raccoon and rattlesnake are peculiarly North American forms.

C. Neotropical Region. This consists of tropical North America, Central America, West Indies, South America, etc. This region is represented by a great number of forms peculiar to it. For example, the jaguar, llama, peccary, tapir, sloth, armadillo, opossum and New World monkeys with prehensile tails. There are no native oxen, sheep or antelopes.

D. Ethiopian Region, consisting of Africa, south of the Sahara Desert, Madagascar and Mauritius. The characteristic animals of this region are the gorilla, chimpanzee, baboon, lemur, African elephant, hippopotamus, rhinoceros, zebra, giraffe, antelope, lion leopard and ostrich. Some are native *only* in this region.

E. Oriental Region. India, south of the Himalayas, Burma, Siam, Southern China, Sumatra, Java, Borneo and the Philippines. Typical animals of this region are the orang-utan; gibbon; tigers; jungle fowl, the ancestor of domestic fowls; the Indian elephant; the Indian tapir and rhinoceroses peculiar to this district.

F. Australian Region. Australia, Tasmania, Papua and New Guinea. Sometimes New Zealand is included with Australia. This region is unique because of an almost total absence of higher Mammals, the Eutheria. It is the home of Marsupials. The Monotremes are still found there. It has its own characteristic snakes, lizards and birds. New Zealand is characterized as being the home of wingless birds and the lizard-like Rhyncocephalia, peculiar only to this island. The higher animals are few and small.

G. Polynesian Region. This region consists of the oceanic islands of the Pacific such as Fiji, Society Islands, Hawaiian Islands and Samoa. These islands are volcanic in origin, having been formed by relatively abrupt eruptions. The surrounding waters are very deep. The shores are often fringed with coral reefs. Darwin has said that the characteristic vegetation is herbaceous forms of large size such as bananas and palms. There is an absence on these islands of Amphibia and terrestrial land Mammals.

Peculiarities of Distribution. Now, although it is evident that the above-named regions have their own peculiar fauna and flora, yet we find many examples of similar forms occupying different regions. How can we account for the vagaries of geographical distribution? We can, for example, accept the belief in special creation as an explanation. According to this idea, when the earth was created, its different regions were stocked with the various plants and animals now found in them, and forms occurring there today are lineal descendants of the forms first placed therein. This explanation is satisfactory to one who simply accepts it and goes no further. But it will not satisfy the student who begins to investigate. It becomes less satisfactory as the investigation proceeds. After all, it will be noted in the brief discussion that follows, that a *creation* or *beginning* is not denied, in fact it is a necessary part of the natural explanation of geographical distribution. To one who studies the problem, the special creation belief is truly a vagary, a vast puzzle, expressive of the whims of a creator. On the other hand, one who grasps the full significance of the problem moves to a higher plane wherein he sees evidences of the operation of great natural processes, the handiwork and instruments of a truly sublime Creative Force.

We find diverse types occupying territory which as far as climate and other conditions are concerned are equally fitted for both. Darwin says: "If we compare large tracts of land in Australia, South Africa and western South America between latitudes 25 and 35 degrees, we shall find parts extremely similar in all their conditions, yet it would be impossible to point out three faunas and floras more utterly dissimilar." "Or again, we may compare the productions of South America south of latitude 35 degrees with those north of latitude 25 degrees, which consequently are separated by a space of ten degrees of latitude, and are exposed to considerably different conditions; yet they are incomparably more closely related to each other than they are to the productions of Australia or Africa under nearly the same climate."

Explanations of Distribution. The student of geographical distribution takes into account, as Bartholomew says, all available knowledge of plant and animal life and assumes that a process of evolution has taken place. He finds that the information furnished by the geologist as to changes in the earth's surface during geologic time and in the physical conditions is essential to an understanding of distribution. He assumes that this form and that form first appeared in centers of origin, *i.e.*, that they evolved in particular regions from which they migrated in various directions and that their present distribution was determined by barriers of one sort or another. Once having arrived at points far distant from their origin, they were prevented from returning to their original home or there might have been no necessity for so doing. This process has gone on for a long period of time, so long that the human mind cannot grasp any adequate conception of it.

Let us consider a few examples, illustrative of the above.

Effect of Barriers. The Himalaya Mountains extend more or less east and west, north of the equator. They act as a barrier separating Palaearctic Fauna from Oriental Fauna. The country south of the Himalayas is tropical. On the other hand, the mountain ranges of Western United States extend north and south parallel with the Pacific coast line. These do not act as barriers, which separate distinctly different faunas, as is accomplished by the Himalayas.

Peculiarities of American Faunas. A study of the Mammals of South America reveals two natural groups. One group consists of such forms as the sloths and armadilloes, the tree anteater, flat-nosed monkeys, marmosets, chinchillas and tree porcupines, peculiarly South American forms. The other group consists of forms such as the tapir, peccary (a wild pig), llama, many kinds of deer, cats, wolves, rabbits and rats. The animals of the second group, though now South American species and peculiar to it, are nevertheless allied to similar North American species. The first-named group has practically no representatives in North America, with the possible exception of the Canadian porcupine. They are peculiarly South American types. How can we explain this problem?

In the Miocene period of the Cenozoic Era, North and South America were not connected as they are now by the Isthmus of Panama. Fossil records inform us of the prevailing faunas in each region. The Mammals of North and South America in those days were entirely different. Later on, in the Miocene Period, the Isthmus of Panama was formed by elevation, and thus a land bridge made possible migrations of the peculiar South American forms northward and of North American forms southward. The fossil record of the geologic strata of that time gives evidence that this migration took place. It attained its height in the Pleistocene. At that time, however, began the great glacial epochs. During the periods of great cold, both regions lost most of their Mammals. Cold exterminated practically all the forms which had invaded North America from the south. The northern visitors to the south fared better, however. Many of them successfully competed with the native South American forms. The northerners did not retain all their original specific characters, and so today we find in South America two groups of Mammals peculiar to it. One group is peculiarly South American and always has been. It is the older of the two. The other resembles North American types, somewhat modified, due to long sojourn in the south.

Professor W. B. Scott states that North America and Asia have been connected and disconnected many times where Bering Sea and Strait now are. Many migrations in both directions across this land bridge took place, as is shown by the fossil record. Many American forms were derived from the Old World. Some have been here so long that they are considerably different from their Old World relatives. Others, however, are very similar to Old World types. They are regarded as recent immigrations to America. It appears that the present separation of North America and Asia took place recently, so far as geological time is measured. The American bears are forms derived by immigration from the Old World. The musk ox, now limited to America, only recently became extinct in Siberia, but once lived as far west as Great Britain, which at the time was connected with the neighboring mainland across the Channel.

Similar Forms at Widely Separated High Altitudes. Why is it that on the summits of mountains far distant from each other we find similar forms although the faunas at the base of these widely separated mountains are different? Examination shows that the mountain-top forms are arctic types, similar to forms living in a belt below the poles. Darwin explained the peculiar distribution as follows. Long ago the circumpolar belt was occupied by arctic types. The glacial periods came in the Pleistocene. As the wave of ice moved south, the southern forms moved further south and the arctic types moved south behind them. The mountains to the south became covered with ice and the arctic types occupied the country at the lower altitudes. As the glacial period gave way to a warmer climate, the arctic forms then present in the temperate regions of North America and in central Europe as far south as the Alps and the Pyrenees could take two courses. First: they could travel northward again to the circumpolar belt which their ancestors had occupied. Some apparently did this. Second: others could ascend the mountain slopes, as the warmer climate continued, to an altitude where arctic conditions prevail — and there they have remained marooned, as it were, until the present.

Island Faunas. Let us consider the problems peculiar to island distribution. Two types of islands are recognized.

1. *Continental Islands.* Continental Islands at one time were undoubtedly connected with the nearest mainland which they resemble in geological structure. If the separation has taken place within recent geological time and passage back and forth is comparatively easy, then we find great similarities in fauna and flora as for example that of the British Isles and the neighboring mainland. If such islands have been isolated from the nearest mainland for long periods of geologic time by a wide, deep gulf, then the island fauna is likely to be peculiarly unique. Long isolation from the competition characteristic of the vast stretches of a continent does not stimulate such marked modifications and evolution of new types. This is illustrated by the fauna of Australia. The typical mammalian population was marsupial at the time the first civilized men arrived. There were different marsupial types, such as rodent-like forms, carnivorous forms, some herbivorous, some insect eaters, but there were no Eutherians except a species of dog, which had apparently been recently introduced. There are evidences that Australia has been separated from the nearest continent since the Mesozoic. During the long, long ages of isolation and in the absence of marked changes in conditions, there was no stimulus to the evolution of the higher orders of Mammals.

2. *Oceanic Islands* are located at great distances from the nearest mainland. They are the peaks of submerged volcanic mountains. The surrounding waters are very deep. They are fringed or covered with coral formations. They usually have fewer kinds of

living organisms than similar continental areas. Darwin states that although New Zealand is 780 miles long, yet it has only about the same number of different flowering plants as a *very much smaller area* in England. It is also true that species occupying oceanic islands are peculiar to that locality. Furthermore, entire classes of continental land forms are often absent from oceanic islands. Let us consider some particular islands in more detail.

The Galapagos Islands form a group of five large islands and ten smaller islands located about 600 miles west of Ecuador. They are separated from each other by channels of deep water, swift currents, a number of miles apart. In structure and other respects these islands are similar to the Cape Verde Islands off the coast of Africa. But the faunas are entirely different. The fauna of the Galapagos group is distinctly American and that of the Cape Verde Islands is distinctly African.

Certain observations regarding Galapagos Island forms are illuminating. Although the fauna is fundamentally American, yet it is peculiarly Galapagos Islands, secondarily. Sea birds that can successfully navigate great stretches of ocean ways are about the same there as on the mainland. But the land birds, such as finches (Fig. 376), though showing basic similarities to mainland forms are Galapagos Island species. These small birds cannot easily travel over the long distance between Ecuador and the Islands. In some way, long ages ago, their ancestors from South America landed here, and here they have remained, and *isolation* under different general conditions and on special islands has provoked modifications that have produced peculiar types. The birds named cannot *easily* pass from island to island. When the original South American visitors arrived, they became isolated on separate islands and the evolution of special island varieties has taken place. We can understand why each island should have its own peculiar type. The Galapagos Islands are known to possess a unique type of tortoise, a very large form which has given its name to the islands. It is peculiarly a land form and cannot pass from island to island. Hence we can understand why each island, until recently (*i.e.*, before the islands had been visited by men), had its own particular variety of land tortoise. Fossil remains found on the mainland indicate that the present-day tortoises of the Galapagos Islands were derived from mainland forms. There are two kinds of large and related lizards resident here. One is a marine type. This can easily pass from island to island and there is little differentiation between them. On the other hand, there is a terrestrial type probably derived from the same ancestral form as the marine type. But the land lizards cannot move readily from island to island, so we find that each island has its own type.

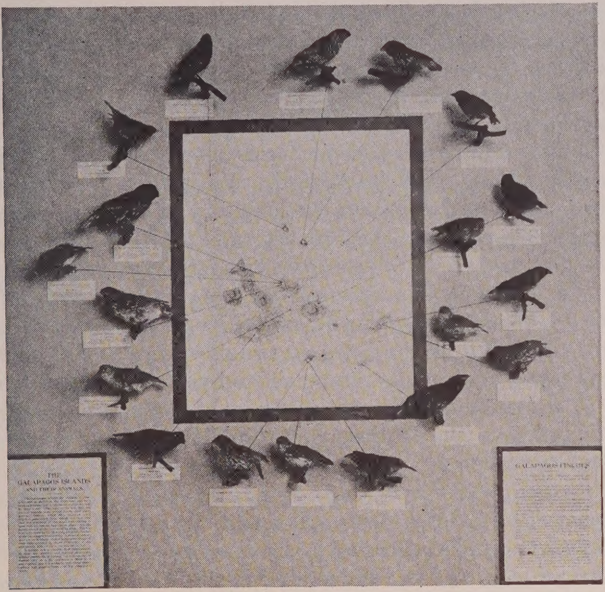

Photo of exhibit in American Museum of Natural History.

FIG. 376. — Distribution of Galapagos Island Finches. The islands probably received their original population from South America. Evolution of species peculiar to the islands is indicated. Darwin wrote: "— seeing this gradation and diversity of structure in one small intimately related group of birds, one might really fancy that from an original paucity of birds in this archipelago, one species had been taken and modified for different ends. — we seem to be brought somewhat near to that great fact — the first appearance of new beings on the earth."
From — *The Voyage of the Beagle.*

The question arises as to how oceanic islands became populated; how the original visitors were able to survive such long ocean voyages.

Transportation over the Ocean. In the "Origin of Species," Darwin, in his discussion of Geographical Distribution, gives an account of many actual experiments which show that seeds can survive long contact with sea water. He indicates possible methods by which animals can be transported over seas. They may be transported in driftwood. Often collections of débris, forming natural rafts, break away from shores of rivers and are carried away possibly hundreds of miles. Insects and birds, favored by gales, have successfully traveled across many leagues of ocean. The chances against mammalian transportation are great. It has been noted that whereas oceanic islands do not possess native land Mammals, yet bats related to the nearest mainland forms are found in them. Wingless insects are peculiar to long isolated oceanic islands. They are probably descendants of accidentally introduced winged visitors.

Amphibians are never endemic forms in oceanic islands although they thrive there when introduced. Sea water is very injurious to them and they cannot survive long immersion in it. There is a notable absence of gales in the region of the Galapagos Islands. There have been few accidental visitors for a long period. However, the Bermuda Islands are about the same distance off the North American Coast, and a number of North American forms are found there which are similar to the mainland types. The problem of transportation is easier, and mainland visitors are more numerous. The Bermudas lie in the pathway of storms from the West Indies and from the southern states and these gales would help the transportation of the types found in the islands.

Conclusion. The present-day distribution of plants and animals is explained by natural forces and conditions. We have evidence that types had their beginning in certain centers of evolution from which they migrated in various directions. They were separated by various barriers, some of which arose after the procession of forms had passed on. Subsequent generations were changed by the new conditions which appeared as time went on. In 1883 the Island of Krakatoa in Sunda Strait between Java and Sumatra was the scene of a great volcanic eruption in which the plants and animals were practically all destroyed. Yet by 1920, there were over 500 species established there again and they are just such forms as are found in the near-by larger islands.

The most widely distributed forms are those most independent of barriers. Examples are powerful flying forms and Man and the forms transported intentionally or accidentally by him.

Analysis of fossil records indicates that the ancestors of certain existent types evolved in a center of origin which may be far removed from present-day distribution. There is evidence that migration in various directions took place. The place of origin may not today possess any representative of present-day descendants. Independent geological evidence throws light on the course of distribution and the reason for it. Examples — the horse, camel and llama.

The organic forms occupying a continental island are related to those of the mainland with which the island was once connected. In many cases geological evidence indicates the former connection. If islands are relatively near the mainland, as, for example, the British Isles, the fauna and flora are very similar in the two localities.

If, however, the continental island has been separated from the mainland for a long period of time by a wide, deep gulf, then although the animals in each appear to have been derived from the same stock, yet the island forms are endemic and also very primitive and possibly in some respects degenerate, having undergone little evolution during the long period of isolation. Examples — fauna of Madagascar, New Zealand and Australia.

The organic forms resident on oceanic islands, which are volcanic in origin, are peculiar and endemic but are fundamentally related to forms found on the nearest mainland from which their ancestors could have been accidentally carried by gales. Insects and birds would have been carried along by air currents, but terrestrial types on floating fragments. Long periods of isolation would account for the development of endemic characteristics. Terrestrial Vertebrates, and especially Mammals, are not likely to be thus transported, and are poorly represented. Amphibians to which sea water is toxic are not found. Example — fauna of Galapagos and Hawaiian Islands.

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CHAPTER XXVI

ORGANIC EVOLUTION

PART I. ADAPTATION

Introduction. Adaptation has been defined as the state of being adjusted. Every living form is in a state of adjustment to its surroundings. *No adaptations are absolutely perfect.* Successful adjustments are only relatively adequate. If the organism is not adjusted, death occurs. The biologist looks out on the world of living things and sees adaptations everywhere. That living things are adapted seems almost axiomatic.

The Test of Fitness. The environment acts as a sort of examining board. If the organism passes the test, it survives; if not, it perishes. Charles Darwin in his theory of Natural Selection emphasized this aspect. H. C. Bumpus made a collection of English sparrows overcome by a severe winter storm. He found that those that died were extreme variants, either larger or smaller than the average sparrow. Each organic form is exposed to the constant environmental test, the outcome of which is survival or death. In sudden catastrophes, survival possibilities are part of the very constitution of the survivors. Environmental changes of an extensive or severe sort change the face of nature. Volcanic eruptions pour fourth lava streams which destroy all life remaining in their path. Leonardo da Vinci found marine fossils on mountain slopes and concluded that those high places were once beneath sea level. The geologist has confirmed this and also tells us that one-time elevated lands are *now* far *below* sea level.

Could life, as we know it, continue to be, if the force of gravity were permanently altered; if only blue or red light rays shone upon the earth; if the air were permanently dry or, on the other hand, saturated with moisture; if the percentage composition of the ingredients of air were shifted about; if the temperature conditions in our zone were changed considerably, up or down the scale?

Henderson, in his book, "The Fitness of the Environment," shows how the life we know is fitted for the present type of environment. The environment constantly tests the organism as to its fitness for survival.

Reaction to Environment. On the other hand, however, the organism does not remain supine but actively responds to external stimuli. We must not look upon the organism merely as helpless clay in the hands of molding forces of nature. The organism is part of nature, so constituted as to react specifically to this or that particular variation in the external world. The organism is stimulated to reactions of adjustment and very often succeeds. The sufferer from disease maintains an optimistic attitude because of this great power of protoplasm. The epidermis at the base of each finger is of moderate thickness when we are engaged in light tasks. But if we wielded a pick or hoe, day in and day out, the epidermis at friction points "grows" thicker, forming callosities protecting the tender structures underneath. It is not the pick which makes the callosities because these are a product of tissue activity. The heavy labor stimulates, it is true, but the adaptation is a reflex reaction on the part of the organism. It sometimes becomes necessary to remove a large vein from the leg. This can be done safely because some other vein enlarges and takes on the function of the diseased vessel. There is only one spleen and it is a useful organ, but it is necessary at times to remove it. This is not fatal because other organs take over the work of the spleen. The legless man who exercises develops strong and effective arms. Trees grow well in fertile soil, but some of the same sort do remarkably well in the crevices of rocks. After all we should not think of natural selection as entirely determining which is fit and which is unfit, because many organisms automatically endeavor to become fit.

An Example of an Adapted Organism. A study of any organism will show how fitted it is for its particular mode of existence. The earthworm lives in a burrow and the shape of the body conforms to this. The size is fitted for the use of the setae in crawling in and out of its burrow. They act as a system of levers whose outer ends are in contact with the wall of the burrow. There is no room and no need to turn about in the burrow, for the worm can move easily in either direction. Moreover, it can extend its burrow by "eating" the earth ahead of it. It swallows the excavated earth and secures whatever food there is in it. The earth particles pass through the intestine and, while still there, are carried back up to the burrow entrance, where they are discharged. The skin of the worm must remain moist, otherwise it would die from oxygen starvation. A moist skin is also essential to the functioning of the sense organs in it and so the worm spends most of its time in the ground; and if the surface ground is dry, the worm remains deep in the burrow where the walls are damp. The mouth is adapted for the kind of food the worm eats, and the crop and gizzard are adapted to preparing the food for digestion. The long intestine and its typhosole are well adapted to the slow movement of food, thus giving time for its digestion and absorption. The peristaltic movements of the body churn the coelomic fluid containing absorbed food, back and forth, bringing it into contact with internal tissues that need it. The worm has no eyes nor ears, but is sensitive to light and earth vibrations or jars. It feeds on the surface at night and when all is still. The slightest jar or flash of light will send it scurrying into its burrow. Organisms as a whole appear to be well adapted for their conditions of living.

Organs Are Adapted. The broad symmetrical caudal fin of the Teleost is adapted to forward-moving locomotion, while the asymmetrical heterocercal tail of the shark enables it, at will, to descend to the bottom after food. The wing of the bird is adapted for aerial navigation, and the wing is modified according to the nature of the flying habits of each particular species. The beak of the seed-eating bird is differently organized from that of the flesh-tearing eagle. The crop of the seed-eating bird is adapted for temporary accumulation of grain during short periods of adventure in the open where the bird may be exposed to the eyes of a possible enemy. The opposable thumb and great toe of the chimpanzee are adapted to arboreal life and the long, strong front limbs are adapted to swinging the body along from limb to limb. Although the hind legs assist in this, they are also used for support. The swiftness of the race horse is made possible by the one-toed organization of the foot and the skeletal, muscular and nervous organizations are directed to this end also.

Functions Are Adapted. Think of the different and special functions of the front limbs of the bat, the camel, the horse, the cat and the chimpanzee. The organization in each case fits the function which is performed. We examine the skeletal structures of all and compare them. We find a similar underlying pattern. It is the function which determines the specialization in structure in each case. A piece of the tendon of Achilles, which connects the calf (gastrocnemius) muscle of the leg to the heel, is torn away by accident. If the leg is prevented from being used, a sort of connective tissue regenerates and fills the space thus formed and the use of the leg is greatly impaired. But if the movement of the leg is permitted and encouraged, useful tendon tissue regenerates to repair the wounded tendon and so in time restore the leg apparatus to a normal functioning condition. If the spleen is removed, the function is taken over by other glands. If the thyroid gland does not deliver sufficient thyroxin to the body, it may grow larger, forming a goiter, in an endeavor to salvage every trace of iodine ingested. When the color of the background changes with the seasons, certain physiological activities change the plumage of certain birds accordingly. The breeding period of the frog and other animals is in the spring and the young appear when the food and climatic conditions are favorable for successful development.

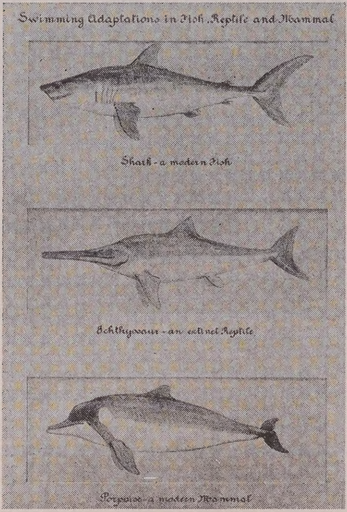

Swimming Adaptations in Fish, Reptile and Mammal
Shark - a modern Fish
Ichthyosaur - an extinct Reptile
Porpoise - a modern Mammal

FIG. 377. — Illustrating the Law of Convergence of Form — Osborn. (Courtesy Am. Mus. Nat. Hist.)

Embryological Processes Are Adaptive. The gastrula of the starfish and Amphioxus are adapted to a freely moving life so that they can obtain the necessary food for the completion of their development. The embryos of Fish, Frog, Reptile, Bird and Mammal look alike at an early stage. Different developmental processes in each result in a special type of adult. Both pairs of legs of Necturus, an Amphibian, are about equal in size. The embryonic legs of a kangaroo at an early stage are equal in size, but later the front limbs develop very slowly and very little, while the hind legs develop rapidly and become very powerful organs. The nose of the elephant develops more rapidly and differently than the nose of a tapir and the neck of a giraffe develops more rapidly than the neck of a cow, while the brain of a scholar develops differently than the brain of an idiot.

Law of Convergence. H. F. Osborn maintains that two great laws of adaptation are evident. One he calls the *Law of Convergence of Form* (Fig. 377). This is illustrated by adaptations for rapid swimming. The internal anatomy of the shark is that of an Elasmobranch; that of the Ichthyosaur is reptilian; that of the porpoise is mammalian. The Shark, the Ichthyosaur and Porpoise all have a spindle-shaped body, bulky in front, a pointed nose, a propelling tail, a dorsal fin which acts as a keel and anterior appendages used for balancing. Structures somewhat similar in form are seen in adaptations for flight illustrated by the "wings" of insects, and of pterodactyls, the flying reptiles of the Mesozoic Era and by bats and birds.

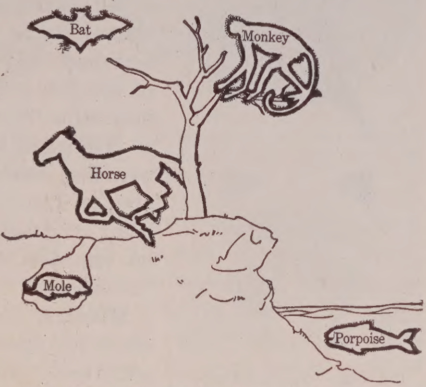


FIG. 378. — Illustrating the Law of Adaptive Radiation — Osborn.

The Law of Adaptive Radiation (Fig. 378). This appears to be just the opposite of the preceding. Animals of the same sort take up different modes of life and, becoming adaptively modified for each particular mode of life, assume different forms. Mammals which have a similar fundamental organization are adaptively modified to different life conditions. We find running or cursorial types, such as the horse; burrowing or fossorial types, such as the mole; climbing or arboreal types, such as the monkey; swimming or natatorial types, such as the porpoise, and flying or aerial types, such as the bat.

Protective Resemblance. Protective resemblance is a sort of convergence of form and color exhibited by many animals in particular habitats. The polar bear and other animals in the same regions are white, living as they do midst arctic snow and ice. The ptarmigan assumes a white coat in winter, the flounder changes its color to blend with the color of the bottom; Kallima, a butterfly (Fig. 379) from India, folds its wings as it rests on certain twigs, and then looks like a dead leaf. Certain moths are so colored as to blend in with the color of the bark of the tree on which they rest. A certain insect resembles a thorn and rests on thorny branches. According to some observers, the striped tiger blends in with the jungle through which it courses, the tawny lion fits in with its background of tall dried grass and the leopard's spots cause it to be unseen among the lights and shades of leafy branches. The belly of the fish is light in color and is unnoticeable from below, while the back is so colored as to blend in with the surrounding water in the dim light from above. Protective resemblance is agreement in color, form or both, between an organism and some part of its environment.

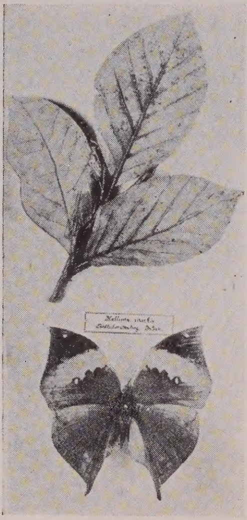


FIG. 379.—Kallima Butterfly of India. Lower figure with wings outspread. In upper figure, the butterfly is at the lower left and at rest. (Photo by Schechter.)

Mimicry. No less striking is mimicry, which is a special kind of protective resemblance. In this sort of adaptation, a defenseless species apparently secures protection by possessing a close resemblance to a form that is well protected. The defenseless form *mimics* certain rather *immune* models (Fig. 380). The models have distinctive colors or markings by which they are recognized, with the result that they are avoided. Certain harmless flies, moths and beetles look like, *i.e.*, *mimic* protected forms. Some flies "buzz" and have the appearance of bees. Some edible butterflies imitate, in appearance, nauseating forms. Mimicry is not a conscious reaction on the part of the mimics. The idea of mimicry is a human conception. One naturally asks, "How did it come about?" The student of mimicry and protective resemblance and convergence of form holds that such adaptations were perfected by a process of the survival of the fittest.

Adaptive Modifications. Organs and tissues are modified to become special adaptations. Tissues and organs used once for one purpose are modified for functioning differently. The muscle tissue of the pectoral fin of the electric ray is now an electric organ, giving its enemies a severe shock whenever they come in contact with it. The mammary glands of Mammals are modified oil glands. Feathers of Birds and fur of Mammals are modified scales of Reptiles. The Eustachian tube of our middle ear is the modified old spiracle of the dogfish put to a new use.

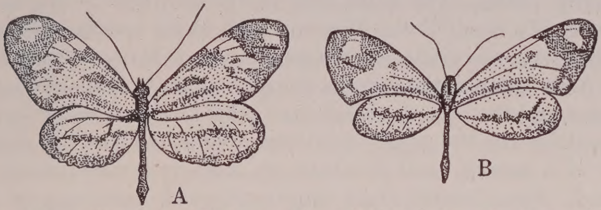


Fig. 380. — Illustrating Mimicry. Fig. A is Heliconius, a butterfly which is the model for B, Mechanitis, which mimics A. A is nauseating to taste and birds avoid it. B is not, but is protected. Both from Honduras.

Parasitic life has brought about extensive modifications resulting in adaptations of dependency. In the case of the tapeworm, organs of locomotion and sense organs, no longer needed for adjustment, disappear. The digestive tract also disappears. Under the special conditions of life the chance of completing the life cycle is reduced. To meet this situation, an enormous number of eggs and sperm and even embryos are produced. In some cases the embryonic form of the parasite is similar to that of related independent species, but degeneration later appears.

Degeneration and modification of organs do not always lead to parasitism, but sometimes to adaptations for a special mode of life. The tadpole of the Tunicate is a free-swimming animal, but as it develops, the tail and notochord and most of the central nervous system disappear and it becomes an adult sedentary animal but is not parasitic. Fishes that live in caves have degenerate and, so far as we know, useless eyes.

Commensalism. Certain adaptations result in an association between two forms with no harm to either. Such an association is known as commensalism. Fierasfer, a peculiar fish, spends most of its time in the gastric cavity of a sea cucumber, from which it emerges at times for brief periods to capture food. The form of the fish has become fitted to this environment. You may have seen the little crab that lives in the shell of the living oyster. The shark-sucker is a Teleost that has a sucker-like pad on the top of its head and although its locomotor apparatus is weak, nevertheless it makes long journeys because it attaches itself to the body of a shark and is thus carried about.

Symbiosis. There is another special adaptive association known as symbiosis or living together. In this case the two forms mutually profit. The green color of Hydra viridis is due to the presence of a small Green Alga and both forms benefit. A lichen is a symbiotic association between an Alga and a filamentous Fungus. The Alga makes carbohydrate, some of which is available for the Fungus, and the Fungus absorbs and holds moisture, some of which is available for the Alga. The hermit crab lives in the cast-off shell of a marine snail to which sea anemones may become attached. Some hermit crabs deliberately seek anemones for this purpose. The anemone can ingest floating fragments of the crab's food and the crab possibly gains concealment due to the presence of the anemones. We have already called attention to the association between ants and plant lice.

Conclusion. The observation of so many differently adapted forms, which in many cases comprise groups whose members are fundamentally similar from a structural point of view, have forced the philosophical investigator to the conclusion that modifications of an original type pattern have taken place and that the special forms have been *derived* from an original ancestral type, which was generalized in structure. As an illustration of this, the various orders of Mammals have been derived from an ancestral generalized Mammal.

Adaptations due to the effect of environmental conditions on the actively reacting organism are closely concerned with *Organic Evolution.*

PART II. EVIDENCES FOR ORGANIC EVOLUTION

Introduction. The great mass of biological facts, of various kinds, leads to the formulation of the *theory of organic evolution* as a fundamental life principle. It is the business of the scientist to discover the laws according to which phenomena operate, and the biologist finds that the history of living forms and what they are today involves a process of evolution. The principle of evolution is not limited to the science of biology but is also a fundamental conception in astronomy, geology, chemistry and physics. As a matter of fact the principle of evolution is evident to all who read the daily newspaper understandingly. Human history is a story of evolution. We are all familiar with the evolution of mechanical contrivances, evolution in medicine, in politics and in education.

It is not the business of the biologist to discuss the *Original Cause* or *Creator* of Things.

There are great classes of facts that bear witness to the truth of the theory of organic evolution. These are the facts of (*a*) Palaeontology; (*b*) Geographical Distribution; (*c*) Comparative Anatomy; (*d*) Embryology; (*e*) Classification; (*f*) Physiology; (*g*) Experimental Evolution. Let us study each of these.

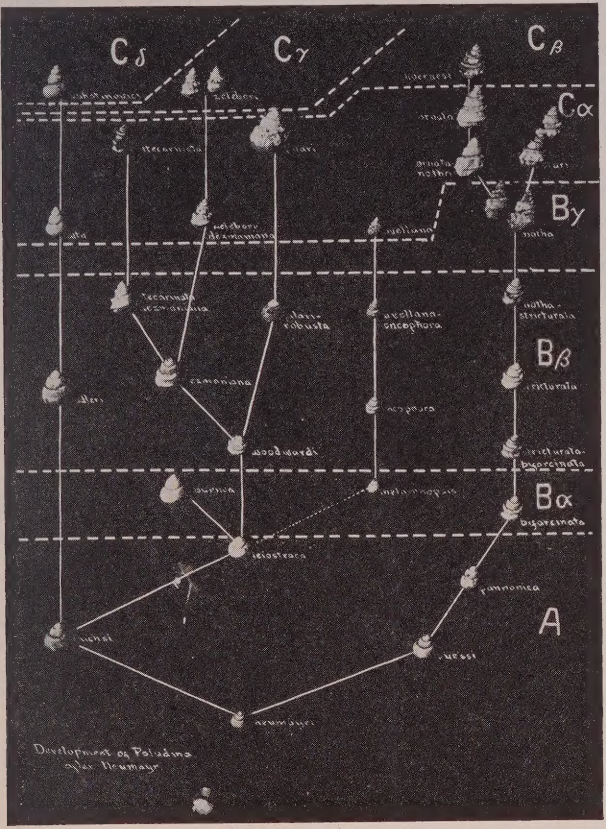
(*a*) **Palaeontology.** The geologist studies the distribution of, characteristics of and agencies concerned in the formation of sedimentary rocks which form a more or less continuous mass at the surface of the earth. The geologist recognizes certain definite rock strata which he can identify at widely separated points. He tells us that elevated lands, now far above sea level, once formed the bed of an ocean. He describes mountain-forming, great climatic changes, ice ages; and he presents to us the history of such great changes in the past.

He concludes that sedimentary rocks have accumulated in thickness for a depth of about seventy-five miles. He estimates that a long period of time has elapsed during which this sedimentation and rock formation took place. By utilizing certain data, he estimates that this took between five hundred million and one thousand million years. He divides geologic time into *Eras*. We have already studied a brief account of the life during these Eras. We noted that during the long and primary Archezoic Era there were no organic forms since these basic strata have no fossils.

Succeeding these rock formations are those of the Proterozoic Era in which there is a great paucity of fossils. At any rate, very few have been found there as compared with the richness of finds in the next Paleozoic strata. The Paleozoic Era was a time of dominance of marine Invertebrates and lower plants. The order of appearance of the index fossils corroborates conclusions as to age and order of appearance arrived at by other methods of reasoning and other kinds of observations. In offering the facts of palaeontology as indicators of the process of organic evolution, the student is referred to the discussion of the *distribution of animals in time,* already presented. We note here, however, some general conclusions from those facts. First: Organisms of the highest (newest) strata are most like living forms and they are also the most specialized. Second: Organisms of the lowest (oldest) strata are most generalized. Third: There is a gradual progression from simple generalized forms to complex specialized forms. Fourth: Many types of plants and animals which appeared in early times, flourished for ages and became extinct. Fifth: Lines of increasing specialization with consequent extinction have been worked out. Sixth: As time went on, *new types* appeared and these were *more specialized* than the older types (Fig. 381). Seventh: More specialized types emerged from what were already comparatively specialized types, as, for example, Mammals from reptilian ancestors. Eighth: Most of the Invertebrates had already been well established during the earliest known life strata. Ninth: Since skeletal structures lend themselves best to fossilization and since at the same time they are good indices of organization, it follows that *vertebrate* palaeontology would probably be well developed. Vertebrate palaeontology presents a wealth of evidence for the theory of organic evolution, as evidenced by what we know about such forms as the horse, camel and elephant. Tenth: The fossil history of one part of the earth's surface agrees in general with that of other parts. One general science of palaeontology is possible.

The question is often asked: "Why do we not find missing links oftener?" For one thing, it is only where natural forces have so lifted and broken the strata that we have any hope of being able to find fossils, and most of the earth's crust is closed to fossil hunting. Again, all the fossil collections in the world comprise but a very small part of all the fossils entombed in the rocks. In fact no museum in the world contains *all* forms which we *think* exist. New collections are constantly being made and, of course, new fossil forms are being discovered. It is only recently that fossil hunting has been adequately undertaken. Finally, modern biological thought does not demand a completely graded series of forms since origin of species by mutation is a possibility.

(*b*) **Geographical Distribution.** Any plausible explanation of present-day distribution of faunas and floras on the earth's surface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Cβ
Cα
Bγ
Bβ
Bα
A
hoernesi
ornata
ornata-notha
notha
notha-stricturata
stricturata
stricturata-bifarcinata
bifarcinata
pannonica
suessi
neumayri
fuchsi
leiostraca
eburnea
woodwardi
avellana-oncophora
oncophora
Development of Paludina
after Neumayr

FIG. 381. — Evolution of Paludina, a snail, as shown by fossil shells taken at different geologic levels. After Neumayr. (Courtesy American Museum of Natural History.)

involves the principle of *organic evolution* and of *geologic evolution.* We have already discussed this in the chapter on *geographical distribution.*

(*c*) **Comparative Anatomy.** In our discussion of comparative anatomy and of adaptations, we found that a comparison of the various systems of organs of animals led us to arrange them in groups of increasing complexity and that such studies suggest the idea that more specialized forms could have been derived from organizations like those possessed by simpler types, or in other words, that we could explain the progressive modifications by a process of organic evolution. It seems reasonable to conclude that closely similar animals are closely related. Vertebrates have sufficient similarities in common to warrant the conclusion that all are related. If we tabulate the structural organization of such organs as the skeleton of the limbs; and chambers of the heart; the parts of the brain and cranial nerves; the ear, the intestinal tract of Elasmobranchs, Fishes, Amphibians, Reptiles, Birds and Mammals, we find an exposition of evolution.

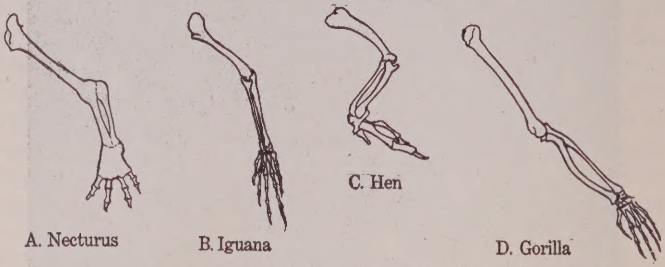

Fig. 382. — Homology shown by structure of fore-limbs of vertebrates.

The case is made still stronger when we set down the embryology in each case. If we extend our study to particular organs in several types of the same class which exhibit special adaptations, we find that the case for evolution appears to be still stronger. For example, let us consider the fore-limb structure of man, dog, bat, horse and deer (Fig. 382). The limb plan of the man and dog seems to be more like that of the generalized vertebrate fore-limb, and those of the other three Mammals appear to be specialized limbs. We say that when the use of the limb becomes specialized, then the structure of the limb is accordingly modified from the generalized plan. On the other hand, when we compare the limb and brain of Man with that of the Reptile and Elasmobranch, to name widely different groups, then we find that although the human limb appears to remain more or less generalized, yet his brain is very much specialized. A study of the comparative anatomy of Urodela and Anura leaves the impression that Anura are, so to speak, specialized Urodela and that Urodela are more like fishes than are Anura. A comparison of the anatomy of Arthropods and Annelids reveals many annelid characteristics in the former group. The tabulation of the facts of comparative anatomy alone would enable us to arrange phyla, classes, orders, families, genera and species of animals in a very satisfactory phylogenetic order, *i.e.*, such an arrangement would represent fairly well the order of evolution of those forms. And this can be done with plants as well as animals.

(*d*) **Embryology.** But the facts of embryology go hand in hand or corroborate those of comparative anatomy. The mere fact that all Metazoa begin life as a single cell is in keeping with the notion that all Metazoa are descended from some kind of Protozoan ancestor. Some people find it difficult to think it possible that man has been evolved during long, long ages from a remote protozoan ancestor. However, *it is a known fact that a human being is evolved during the short space of nine months from a microscopic speck of protoplasm, the human fertilized egg.* This known *fact* of ontogeny is no less marvelous than the other *theory* concerning his phylogeny. A comparison of development of different groups shows cleavage stages, gastrula stage, appearance of ectoderm, endoderm and mesoderm, and organ formation proceeding in much the same order if we allow for the special adaptations in each case. The similarity is great enough to be considered significant evidence of phylogenetic relationship. We do not expect that an Arthropod in its development should pass through a specialized echinoderm and molluscan stage, for Echinoderms and Mollusks, as we know them, appear to represent *different lines of evolution* from that of the arthropod. However, we should expect to find something in common between all three in their early development and we find embryological facts which connect these three phyla as well as all the other metazoan phyla. The recapitulation theory, once so widely followed, claimed that ontogeny recapitulated phylogeny, *i.e.*, that an individual in its development revealed stages through which its species passed, or in other words its evolutionary history. In our study of embryology we criticized the too literal interpretation of such a principle. Haeckel insisted upon complete application of this so-called law, but consequent research proved its limitations. However, the facts of comparative embryology (Fig. 383) compel the retention of the general truth of recapitulation. A study of the foetal membranes and placentas of Mammals is greatly amplified by a knowledge of their formation, but they are not understood until we view them from the point of view of the yolk sac, allantois and amnion of Reptiles. Mammalian and avian gill slits become meaningless until we compare their embryology with the phylogeny of gills in Fishes and Amphibians. The comparative anatomy of the heart and its great vessels in Vertebrates is understood when we take into consideration at the same time the embryology of the same structures in representatives of each class of Vertebrates (see page 386). We can understand the kidneys and urino-genital ducts of the Vertebrates series only when we know the embryology of these structures (page 389) in each case. All of these studies indicate a process of evolution.

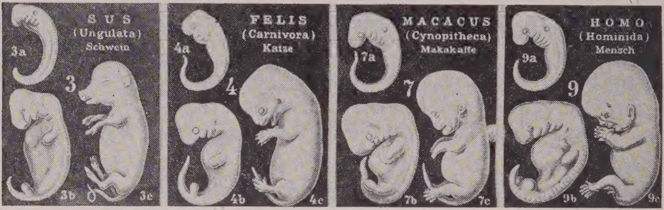

FIG. 383. — Similarity in early embryos of mammals, *i.e.*, reading from left — Pig; Cat; Monkey; Man. Gill slits are shown in earliest stage. From Haeckel. (Photo courtesy American Museum of Natural History.)

The evolutionist holds that Cetacea were land Mammals which, during mammalian evolution, turned to the sea. As Mammals they should present indications of hair and hind limbs, which are lacking, and although some Cetaceans have teeth, others have none. Yet, the embryos have hair and embryonic hind limbs and the adult toothless forms have embryonic teeth. Modern birds have no teeth and yet the embryos of some types have them and so did Archaeopteryx, the reptile-bird of the Jurassic Period. The lower Mammals have two distinct oviducts, as have the lower classes of Vertebrates. The primate embryo has two distinct oviducts, but there is a progressive fusion from behind forwards, forming the single vagina and uterus (Fig. 271). In adult Ruminants such as oxen, sheep and goats, there is no collar bone (clavicle), but this forms in their embryos and is later absorbed. Embryology shows that many adult parasites, without appendages, muscles and other organs, are degenerate descendants of more complicated independent forms. Embryology allies the horseshoe crab with the Arachnids and not with Crustacea. Embryology links crab-like forms with lobster-like types. Embryology, by way of the trochophore larva, links several phyla of animals (see Fig. 173). Serpents now have no limbs, but embryology indicates that they were derived from an ancestor that possessed limbs, and the python has remnants of the hind limbs in its body. Rudimentary and now useless structures, found in many animals, are explained on the theory that these animals are descendants of ancestral forms which possessed the fully developed form of such structures. The study of comparative histology makes the case for evolution still stronger.

(*e*) **Physiological Evidence.** The fact that all animals and plants have to perform about the same general functions, in order to live, is evidence of their relationship as well as the fact of the fundamental similarity of all protoplasm and the chemical reactions that take place in it. If we narrow the problem down to the general physiology of *animals*, we find further similarities, as, for example, in the nature of necessary food and the known types of products of metabolism. Animals which are considered related on other grounds exhibit more similar physiological processes. Mammals other than man react to bacterial poisons in much the same way as man. This fact makes it worth while to conduct experiments on the lower animals, and the results prove of the greatest value in the treatment of human disease. In the reverse fashion information concerning human pathology is of use in the treatment of disease in animals. Antibodies, antagonistic to the diphtheria germ, are produced in the horse and are injected into the human blood system in an effective treatment of diphtheria in man. Against smallpox in man we use vaccines which have been produced in other Mammals. The entire vaccine and serum treatment is based on the proven knowledge that the physiology of the Mammals is to a certain extent similar, and this indicates their relationship.

Of more precise moment are the evidences furnished by the so-called blood tests, *i.e.*, the application of the *precipitin reaction* of various bloods to the questions of phylogeny. The great work in this field was done by Nuttall of England and his collaborators, and results appeared in a book entitled " Blood Immunity and Blood Relationship " in 1904. This volume records results of thousands of experiments which constitute a physiological evidence for evolution.

Before presenting any results it is necessary to understand the methods used. A quantity of fresh human blood is taken and allowed to clot. A clear yellowish serum, freed from corpuscles and coagulating ferments and products, is obtained. Very small quantities of this serum (1 cc. to 2 cc.) are injected at intervals (two days, for example) into the veins (circulation) of a rabbit. The body organization of the rabbit reacts to the introduction of this foreign substance. An anti-body (antagonistic substance) is formed in the blood of the rabbit to counteract the toxic-like human serum. *The injection of a large quantity of human serum all at one time would have killed the rabbit.* The anti-human-serum-body formed in the rabbit is roughly comparable to the antitoxin produced in horse blood when diphtheria toxin is intravenously injected into the horse. This periodic treatment of the rabbit is continued for some days, then is discontinued. A waiting period of a few days follows. Blood is now obtained from the rabbit, and from this a clear *rabbit serum.* If a drop of human serum is *now* added to the above, a white precipitate develops which is an index of the neutralizing effect of the modified rabbit serum on the toxic human serum. The method can be used for other purposes. For example, if a few drops of a clear, saline extract of an old human bloodstain are added to such rabbit serum, a white precipitate is also formed. Although the bloodstain may be many weeks old, a positive result is obtained. If this immunized rabbit serum is tested with blood serum or bloodstain extract from other animals such as chicken, dog, cat or cow, no precipitate is formed.

This is a delicate and certain test for human blood and is, therefore, made use of in criminal cases in the investigation of suspected bloodstains. It is known as the *precipitin test.* The rabbit can be immunized, however, against the blood of any animal. If cat serum is repeatedly injected, the rabbit serum will give a precipitin reaction to cat blood. Nuttall and his co-workers employed this method to investigate blood relationship among animals. They not only immunized rabbits to blood of animals of as many different orders or families as they could secure, but they also secured bloodstains from a great variety of animals all over the world.

Finding that a hunting expedition was starting for Africa, these investigators provided it with material for obtaining and preserving specimens of blood from all the animals captured. If an animal was killed, the hunter soaked a small sheet of filter paper in the blood. The stained paper was pinned up to dry. It was then placed in an oiled-paper envelope and sent to Professor Nuttall. The experiments indicate close relationship between man and the apes, the precipitate with ape blood being more like human blood than monkey blood. All Carnivores have a similar blood. If anti-cat serum is used to develop immunity, then the mmune serum shows that the various cats are more closely related to each other than to dogs or wolves. Anti-deer serum gave a good reaction with serum from antelopes, goats, sheep and oxen. Anti-izard serum gave the best reaction with the blood of lizards but very good with that of snakes and better than with that of Che-onia or Crocodilia, thus supporting other evidence for considering snakes and lizards to be closely related. This test indicated the relation of the horseshoe crab to other Arachnids rather than to Crustacea. We have stated, in the first part of this section, that the blood of the different orders of Mammals is similar. Here t should be emphasized that in more particular respects, each order has specific differences. It is reactions of the present type that indicate the more particular differences. Large quantities of foreign blood injected at one time into an animal will cause death. We could not use sheep's blood in human blood transfusion. In fact we must use only human blood of the particular type as that of the patient and there are a number of types. Notwithstanding this, the fact remains, as stated in the words of the above investigators, " a *common property has persisted* in the bloods of certain groups of animals throughout the ages which have elapsed during their evolution from a common ancestor, and this in spite of differences of food and habits of life." The blood tests indicate a genetic relationship between different species of the same general kind.

(*f*) **Classification.** How foolish it would be to classify stamps as to color or books as to size or animals as to habitat. Such methods of classification mean chaos. Taxonomists have what they call a natural classification in which the data are largely morphological and in which the underlying principle is descent with modifications or organic evolution. This system of classification was "invented" by Linnaeus (Fig. 384) about the middle of the eighteenth century, and published in his "Systema Naturae," which presented an orderly classification of plants and animals. In this scheme of classification Linnaeus devised several kinds of groups, extending from the most general and inclusive to the more circumscribed and specialized. In current terminology, the European wolf belongs to the *species lupus.* But the several *species* of wolf-like animals constitute the *genus Canis.* Linnaeus adopted the scheme of *combining the name of the species with that of its genus to identify it.* The house dog is *Canis familiaris.* Wolves, foxes, hyenas, jackals, all belong to the *family Canidae,* all being wolf-like or dog-like forms. The Canidae, Felidae (cat family), Ursidae (bear family) and the aquatic seals and walruses constitute the *order Carnivora,* or flesh-eating animals. The Carnivora, Cetacea (whales), Rodentia (gnawing form, like rats), etc., form the *class Mammalia,* which are all fur-bearing.

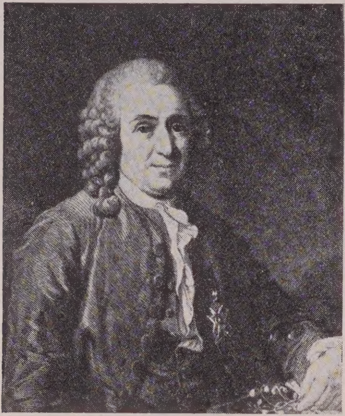

FIG. 384. — Linnaeus, Taxonomist. Linnaeus originated binomial system of naming plants and animals.

The Mammalia, Aves (Birds), Reptilia, etc., have an endoskeleton with a jointed backbone and hence are members of the *sub-phylum Vertebrata* of the *phylum Chordata.* Chordata, Mollusca, Arthropoda, etc., constitute the *kingdom Animalia.*

Not all of the names or subdivisions now in use were devised by Linnaeus nor is the classification necessarily the same. Linnaeus, on the whole, thought that each species was a separate creation and stated as much. He denied the principle of organic evolution. But one who collects great numbers of individuals of any species soon recognizes the great variation among them. If the form has a wide geographical range, then those at the extreme limits may appear to be separate species and would probably be so considered if nothing were known of the intervening forms; but, one notes a gradual transition from one type to the other when the whole series is at hand. At the same time, the differences suggest that the ancestors of all may have migrated from one place of origin or introduction and that the variations present have been due to long residence in different places under different conditions.

The taxonomist finds that if he adopts the principle of organic evolution he has the most satisfactory method of classifying animals and plants. The modern classification is a map of the order of evolution and the genetic relations of organic forms — in short it is a code or formula of the history of organic life. At the same time it is a human device. What we call phyla, classes, orders and families are names of concepts. But such a classification may be pictured as a tree with two large trunks. How shall we describe them? One by the characteristics of all animals, the other by the characteristics of all plants. Both these trunks have a common short trunk near the ground. What is that? We define it in terms of the primitive hypothetical plant-animals, first formed from the inorganic represented by the earth from which this *tree of life* is growing.

Along the line of the animal trunk we see great branches. These are the *phyla.* We describe the chordate phylum by the characteristics of the Chordates. This grows out into two branches, sub-phyla, the Prevertebrates and the Vertebrates. The vertebrate branch subdivides into *order* branches and each of these successively into, possibly, *suborders, families, genera* and *species* and the last, possibly, into *varieties.* The taxonomist holds that all the species of any genus are descended from an ancestor which is described by the characteristics of that genus; that all the genera of a given family are descended from ancestors which had the characteristics of that family and so on, so that all the phyla of the same animal kingdom would have been descendants of an ancestor that had the general characteristics of all animals. Coelenterates are more ancient than the Annelids because they are more generalized and Annelids are more ancient than the Arthropods for a similar reason.

Modern methods of classification support the theory of evolution, because classifications based on this principle are most satisfactory. Sometimes the taxonomist is at a loss to decide upon genetic relationships and it is just these cases that give him trouble in classification and here it is that debate among taxonomists arises.

It is of interest to note that Linnaeus was the founder of this method of classification. He denied the principle of evolution but he *unconsciously applied it.*

(*g*) **Experimental Evolution.** Experiments in plant breeding which have resulted in a new variety may be considered a kind of experimental evolution. As an example of this we have already referred to Professor Biffen's production of a new variety of wheat. Experiments of this sort are constantly being made and as stated (page 485) at present better results are being obtained with plants than with animals. Breeding experiments that have led to the discovery of mutants may be considered as having an evolutionary significance, as, for example, De Vries' evening primrose mutations (page 544) and Morgan's Drosophila mutants (page 545).

In addition to the above we see everywhere evidences of another kind of experimental evolution that has been in progress since human civilization began. The plant and animal breeder has produced many kinds of plants and animals that do not occur in a wild state. Moreover, many of the domestic forms of today are not at all similar to their own ancestors of years ago. Furthermore they are descendants of still more dissimilar wild forms. In other words, we may call the production of domestic varieties a form of experimental evolution. The ancestor of all the many varieties of common fowl was the jungle fowl of India, *Gallus bankiva.* The various sorts of domestic pigeons have been produced from the wild blue rock-pigeon, *Columba livia* of Europe, Asia and China; domestic geese from the native *Anser anser* of England and most of the ducks from the wild mallard, Anas bocas. Domestic pigs of America and Europe have been " evolved " from the wild boar of Europe, *Sus scrofa.* The wild progenitor of our domestic cattle was the aurochs, which was probably hunted by the Goths and even by Julius Caesar's soldiers in ancient Britain. Our domestic horses probably had two wild forms as ancestors and our dogs have probably been derived from two or more wild forms. Gager calls our attention to the fact that over 1600 varieties of pears grown in the United States have been derived from two or three original wild ancestors. And that the 2000 or more varieties of apples have been produced from two ancestral wild forms. Cauliflower, Brussel's sprouts, red cabbage, green cabbage, Savoy cabbage, broccoli and kohlrabi are descendants from a headless cabbage found wild in southern and western Europe.

The objection may be raised that the examples named are not true species. But what is a species? After all it is an artificially created subdivision in taxonomy. Species are the distinctive subdivisions of a genus. Furthermore, members of a species can be interbred and the offspring should possess the characters of the parents. According to this definition, domestic breeds could be considered species. But another criterion of species is that a species is infertile with a different species. This is, in general, true, but not always. The horse bred to an ass produces a mule. Numerous other examples could be given. Let us suppose that an ancestral type has split into two new and more specialized forms. It seems reasonable to expect that if the diversity goes far enough, they would become infertile, for infertility is after all one expression of the specific physiological constitution which has evolved as well as morphological characters. So that, notwithstanding the above criticism, the production of the great variety of domestic plants and animals must be considered as an evolutionary process.

Conclusion. The above classes of facts constitute evidence in support of the *theory of organic evolution.* The word *belief* connotes an emotional state of mind in which *trust* and *faith* in an assertion plays an important part. A *hypothesis* is a *guess* or *surmise* that is assumed to explain a series of associated phenomena. A *theory* should consist of a principle or body of principles derived from all the facts available by standard methods of inductive reasoning. The biologist's conception of organic evolution is a *scientific theory.* No other scientific interpretation of all the facts involved has been advanced. The theory of evolution is one of the major conceptions of biology.

It is well to add a word here to the effect that a process of increasing specialization or evolution cannot *necessarily* continue indefinitely. The astronomer has evidence of the building up and breaking down of systems; the geologist describes the formation and disintegration of rocks; the palaeontologists tell us of the evolution and dying out of great groups of animals and plants; the embryologist describes fertilization, development, maturity and death of the individual; physiology describes anabolism and katabolism. We have no assurance that evolution of organsims will continue indefinitely; we do not *know* that living things will endure; we do not *know* that the planet will persist. Any discussion of evolution is incomplete if it neglects to consider disintegration which is also a natural phenomenon.

PART III. CAUSES OF EVOLUTION

Introduction. As stated above, many lines of evidence indicate that the organic world has come to be what it is by a process of evolution. The idea has somehow spread in recent years that biologists no longer believe in evolution and that it is a discarded theory. This is not the case. The reason for this misunderstanding can be explained. Probably the greatest contribution to the establishment of this theory was made by Charles Darwin (Fig. 385). Darwin not only made the masterly presentation of facts which have led scientific men to accept this theory, but in addition, he presented a possible *explanation of the causes of evolution.* His particular explanation of the factors which cause evolution is known as *Darwinism.* It will be defined presently. It is Darwinism that has been attacked by scientists and not evolution. It should be particularly noted, however, that the chief reason for everlasting fame for Darwin is that he so marshaled the facts in support of evolution that the theory was accepted by the scientific men of his day and is still accepted by scientific men. He advanced the theory of natural selection as a cause of evolution. Not all scientific men regard this explanation as being as all-inclusive as Darwin maintained.

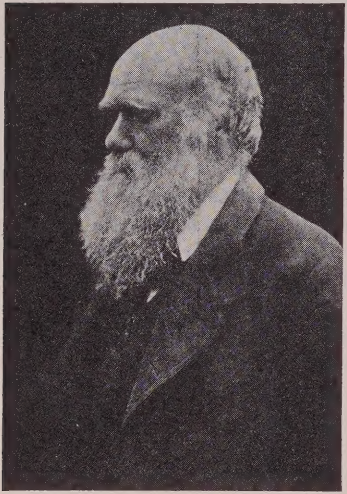

FIG. 385. — Charles Darwin.

Lamarck's Theory. Although there are indications that the idea of organic evolution was present in the minds of ancient Greek scholars such as Aristotle, the first serious attempt to explain its causes was made by Lamarck in his "Philosophical Zoology," published in 1809. Linnaeus, in the middle of the preceding century, had for the first time invented a good method for classifying animals and plants. He had evolved the idea of species or specialized kinds of organisms. He held that they were invariable and constant, that at the creation of the earth, one pair of each kind was created, that all species today are direct descendants of these, that there are just as many species today as were created at the beginning, and that there are no new species.

Lamarck had studied and classified a host of plants and animals and was an accomplished taxonomist. He could not accept the view of Linnaeus as to the fixity of species, and he suggested in its place the theory of evolution. He maintained, what is often lost sight of, that species do not exist in nature, but that the organic world is a vast assemblage of individuals that differ more or less from each other, and that there are all sorts of gradations present. He held truly that species are mere arbitrary human conceptions set up for convenience of classification, that transformations in animals have taken place, and that some of these are so considerable as to cause scholars to designate them as different or new species. He was one of the first to suggest the picture of a tree to elucidate the relations of various kinds of forms. He believed that favorable conditions such as those of soil, food and temperature accompanying changes in the environment would produce changes in plants directly and in animals indirectly; that new physical needs brought about by changes in the environment would call forth bodily changes. Land birds — to illustrate — compelled to take up an aquatic life would develop structures enabling them to swim or wade. He believed that competition in nature brought about changes, that larger forms would try to destroy smaller, and this would produce changes in each, that in-breeding of a race tended to preserve the peculiarities of that race, but that cross-breeding would obliterate the peculiarities of each race involved, also that isolation tended to keep races distinct.

The two great laws of Lamarck are: (1) *The Law of Use and Disuse.* Frequent and sustained use of an organ strengthens, develops and enlarges it; constant disuse gradually weakens it, decreases its usefulness and finally causes it to disappear. (2) *The Law of Inheritance of Acquired Characters.* Everything that nature has caused individuals to acquire or lose by the long effect of external conditions, or by excessive use of an organ or its lack of use, it *preserves by heredity,* and passes on to new individuals which descend from it, provided that the changes are common to those which have given origin to new individuals.

Lamarck attempted to explain the origin of variations by use and disuse, though he gave little evidence for his conclusions. Modifications are produced by changes in the environment and there is also some evidence that these may produce offspring differing from the parent type. But in all these cases it can as well be said that the modified conditions modify the germ cells directly, and if this is true, then it is not a case of acquired characters. The differences in the offspring are not due to changes in the body or somatoplasm of the parent. Most biologists today do not consider that characters acquired during the lifetime of parents are transmitted to their offspring (see page 333). Bouvier, a botanist, took the shoots of a certain plant and set them out at a high altitude. They grew up remarkably different from the plant from which they had been taken. When such plants or their seeds are grown at lower altitudes, they resume the original form. Tower exposed Colorado potato beetles of both sexes to varying conditions of heat and moisture during the time when the egg cells were maturing. The offspring showed distinct modifications and these were hereditary as long as he continued to investigate the matter, which biologically speaking was but a moment of earth history. Furthermore, Tower explained the results as being due to the action of the external conditions directly on the germ cells. As stated before, there is a great body of evidence showing that organisms can be changed by external modifications. There is no evidence that the resulting somatic changes are transmitted to the offspring.

Darwin's Theory of Natural Selection. This was the theory of evolution developed by Charles Darwin in his "Origin of Species" in 1859. "I am fully convinced," he wrote, "that species are not immutable; but that those belonging to what are called the same genera are lineal descendants of some other and generally extinct species." "Furthermore I am convinced that natural selection has been the most important, but not the exclusive means of modification."

To gain an idea of what is meant by evolution by *natural selection,* let us analyze it as follows: (1) *Variation:* The general occurrence of variation is well known. It has already been discussed in the chapter dealing with genetics. (2) *There is a natural tendency toward the over-production of plants and animals.* At times the great wealth of living forms is brought to our notice. Sometimes when the usual unfavorable conditions are not present, species increase in a riotous fashion, as has been shown by the introduction of the English sparrow and the gypsy moth into America and the rabbit into Australia. Darwin pointed out that elephants begin to breed at thirty years of age and a pair may have six offspring in a century. If all the descendants lived and reproduced this original pair would, in 750 years, have nineteen million descendants. For five years Woodruff ran an experiment on continuous reproduction by fission in a certain species of Paramoecium. It can be understood why he did not keep all the offspring, as he computed that the total mass of protoplasm produced would have been 10,000 times the volume of the earth.

Over-production leads to (3) a *struggle for existence.* This may be between individuals of the same kind, — thus newly-hatched lobsters are great cannibals. Young trees growing close together in the forest are rivals. Bachelor fur seals battle for supremacy, the nations of mankind wage war. There is also a struggle between members of different species. Illustrations are the destruction of animals by man, destruction of men by animals. In India, in 1927, 19,069 persons were killed by poisonous snakes, and over 57,116 snakes were killed by human beings. Tigers in India killed 1033 persons and 1068 tigers were killed by men in 1927. (From the *World Almanac* 1930.) The destruction of insects and worms by birds, the destruction of caterpillars by wasps, the destruction of plants and animals by insects, the destruction of animals by Bacteria, are other familiar illustrations.

Animals and plants are also, at times, in fierce encounter with the environment. Death is often the result. The destruction of Pompeii and the earthquake and fire in San Francisco are recalled. Drouth not only kills plants but also animals which die from thirst. Unexpected cold has its victims. These are extreme cases, but a greater amount of less conspicuous competition goes on unseen. As a result of this struggle, out of all that begin life, only (4) *the fittest survive.* Those variations which are best adapted survive, those not adapted perish. These three processes: (*a*) tendency toward over-production, (*b*) struggle for existence, and (*c*) survival of the fittest, — constitute what is known as *Natural*

Selection. Natural selection is necessarily related to adaptations, and those that are best adapted crowd out the unadapted.

(5) Finally only those animals possessing variations with survival value, *i.e.*, the fittest, remain and reproduce such variations. Therefore by *heredity* those advantages secured by natural selection are maintained. A constant succession of selections and further adaptations, generation after generation, results in the origin of new species. Variations of no survival value would not be selected. Natural selection does not originate variations, it merely preserves those that are of benefit under the peculiar conditions of life. It is in no sense a conscious process, but merely mechanical, as automatic as gravity and chemical affinity. Changes in the conditions of life tend to increase variability. Natural selection operates on internal as well as external organs. It is active at every stage in development from birth to death. Some characters are of apparent survival value, as, for example, the teeth of a carnivore. Other characters may be of important survival value although there may be no evident index of it at the time. Those chosen by natural selection have no insurance against accidental destruction.

Darwin was aided in the development of the natural selection theory by a study of *artificial selection* (see below), the process by which various kinds of domestic animals and plants have been produced (Fig. 386). In a sense it may be considered a sort of experimental test of just what selection can bring about. Domestic selection extends far back into human antiquity. Man produces races which are useful to him in one respect or another. Some of these characters would be detrimental in a state of nature. When artificial breeds become feral, they soon revert to a simpler state.[1] In some cases, as in plants, man is able to continue the kind only by successive grafting. The navel orange is an example of this. In the case of many special animal breeds, close in-breeding of pure stock must be practiced to maintain the breed.

Artificial Selection. Artificial selection resembles natural selection. The breeder begins with variations, there is a selection by him of these, and he breeds those selected. Sometimes the selection is general, that is, the breeder simply eliminates the unfit. The result is a general improvement, but does not lead to production of any particular kinds. The breeder may work to secure an all-round, good animal, of large size, tame, fat and

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[1] Even natural forms may not persist. See Chapter XXV.

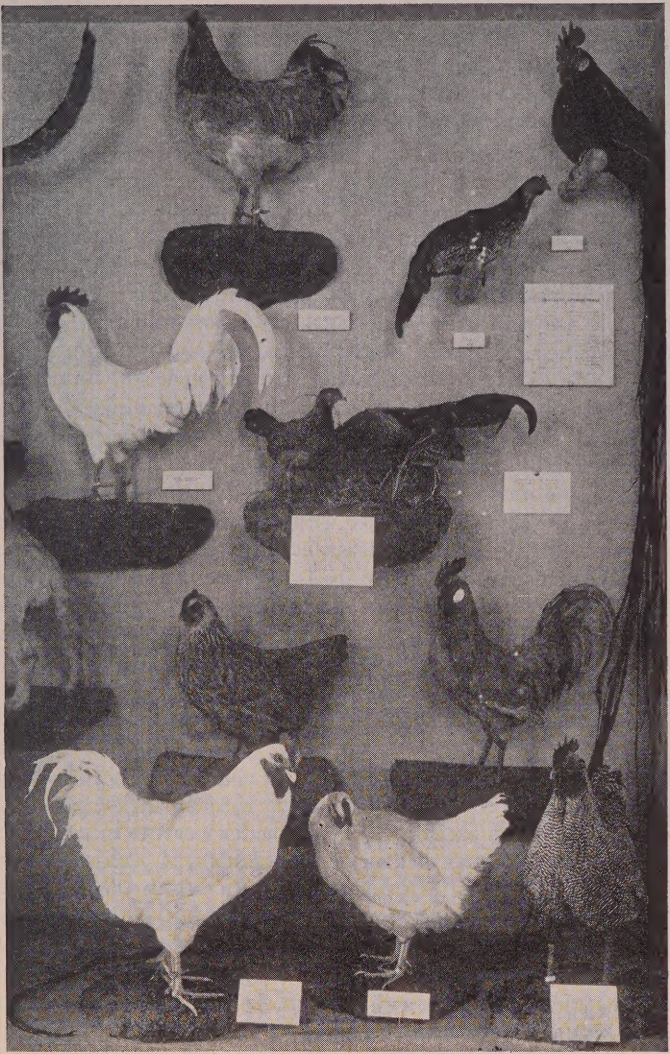

FIG. 386. — Varieties of Domestic Fowls. In the center is the Jungle Fowl of India, the ancestral form. Photograph of exhibit in American Museum of Natural History. (Courtesy Amer. Mus. Nat. Hist.)

fertile. New features may come to his notice and he selects, for mating, pairs that possess this new feature. He may specialize on one character alone, as greater milk production, more meat, more wool or no horns. He also hybridizes, or crosses, two related forms, as was the case of the domestic dog, which is supposed to have been the result of the crossing of the wolf and the jackal. The progeny will tend to vary. And this gives opportunity for further selection. The work of Luther Burbank in this field is unsurpassed. In cross-breeding, wider crosses can be made with plants than with animals. In animals, crosses of varieties are more successful though the offspring may be sterile. Progeny of the male ass with the female horse are mules which are usually sterile. The small hoofs, scanty mane, tail and voice appear to be paternal in origin. The greater size, strength and form come from the mother. The mule is said to be more intelligent than the ass or horse. Cross a male horse with a female ass and the result is a hinny, smaller than a mule but more horse-like. The cross of the male California walnut with a female wild black walnut is a rapid-growing tree with no nuts. Reverse the cross and the result is a tree with larger and better nuts. Speedy race horses have been produced by artificial selection. A speedy horse must have light, slender legs. But there must go with this a certain size and muscular bulk. All increases in speed increase the strains to which the slender legs are subjected, in order to support a great weight in motion.

Heredity in Pure Lines. Professor Johannsen, a Danish botanist, was interested in seeing how far Galton's law of filial regression would work. He thought it might serve as an instrument of continued racial betterment. He planned to select consciously the most exceptional offspring for parents in each generation with the hope of producing a permanent, non-regressive, exceptional stock. He worked with the self-fertilizing bean, *Phaseolus.* He chose nineteen beans of differing size and planted them. He thought that the progeny of the largest would be all large and those of the small bean, small, and so on for all nineteen. As a matter of fact, he found different sizes among the progeny of each. He finally discovered in this variety of bean a number of *pure lines* or races and each pure line had a mode of its own and its own variation about the mode. If he planted a seed from any pure line, the variation in size of its progeny was the variation of that pure line. If one selected beans of the largest pure line in the hope of securing still larger beans, his hope would be in vain (Fig. 387). However, one could secure *large* beans, if only the largest pure line were kept pure. The indication is that selection within a pure line has no effect in modifying the size of beans. The germ cells of plants of any one pure line have the same genes and selection alone cannot modify these. Johannsen, in separating beans into different size groups in the beginning, was dealing with somatic characters. Phenotypes are merely those that have similar somatic characters. Genotypes are those with the same germinal composition. One might select seed of the same size that would be somatically or phenotypically similar, but might be genotypically different and this would be revealed in the variations in the progeny.

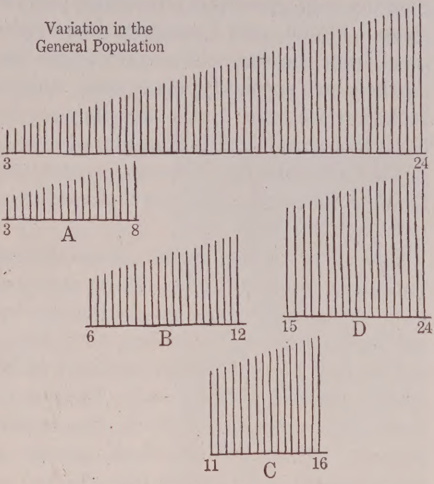

Fig. 387. — Illustrating Heredity in Pure Lines. The main figure above represents variation in the general population. Each vertical line typifies the measure of a certain class and the range is from 3 to 24. Promiscuous interbreeding will show similar results. Selective breeding demonstrates that the whole population consists of several pure lines represented by A; B; C; D. In breeding, any members of Pure Line A will give same range of variation as A, *i.e.*, 3 to 8, etc. The members of any one pure line are similar genotypes. Overlapping members of A and B, for example, are phenotypes. Variation in each pure line is due to the environment, *i.e.*, the individuals do not grow up under same conditions. The mean of each pure line or of the general population is not shown.

Jennings found similar results after he had ascertained pure lines in Paramoecium. Tower, after twelve generations of selection in potato beetles, attempted to establish a dark variety, but without success.

Without giving any further criticisms of the theory of natural selection at this time, it is evident that the study of pure lines shows how inadequately natural selection serves as a complete explanation of the origin of new species.

Theory of Isolation. One of the difficult things to understand concerning natural selection is why new advantages secured by natural selection are not lost in breeding with individuals of an older, simpler sort. It has been argued by a number of workers that *isolation* prevents this. Isolation is a sort of selection which possibly segregates pure lines and permits inbreeding only among them. Gulick and Crampton have shown that valleys, running back from the shore in certain South Sea Islands, are populated by their own special types of snails, which are *fundamentally related.* Isolation preserves types once they are formed. Soil peculiarities, heat, moisture are also examples of possible agents of isolation.

The Marsupials of Australia and the wingless birds of New Zealand illustrate the part played by isolation in evolution (see page 507).

Theory of Orthogenesis. Some biologists do not believe that variations are fortuitous. These investigators believe that variations occur in determined directions, leading to evolution along particular lines. This is due, they say, to the internal organization of that kind of animal or plant, which begins and continues to evolve toward a fixed end. During the process, the external forces are secondary. It is the internal organization that is primary. External influences, climate and food, however, may determine to some extent this internal organization. If this line of evolution produces something of advantage or disadvantage to the species, then natural selection steps in.

One of the reasons advanced against the acceptance of the theory of natural selection is that the small first stages in the development of vitally important adaptive structures would have no selective value. The orthogeneticist claims that structures *appear* that may be adaptive from the beginning. Osborn is convinced that mammalian teeth indicate this. In many orders of Mammals, the teeth develop with a few similar cusps. These cusps arise independently, gradually, along definite lines, until they are adapted for their work. He believes that selection had little to do with this, but that it was due to a predetermined, underlying, germinal constitution. The material obtained for the study of the history of the horse indicates evolution in a straight line, that is, a case of orthogenesis. Conversely, there are examples of evolution in a straight line continuing to a point where the structures are overdeveloped and are a positive menace to the animal in the struggle for existence. Illustrations are those of the great tusks of the wild boar; the antlers of the so-called "Irish Elk," which, at the time of its extinction, bore antlers thought to have been heavier than the rest of the body; the enormous bulk of some of the reptiles of the Mesozoic Era; the great horns and skull frills of the rhinoceros-like Dinosaurs; and the terrible canine teeth of the saber-toothed tiger, Smilodon. Such over-developments might have been "fitted" for the conditions then prevailing. When conditions of life changed, such highly specialized structures caused the extinction of these creatures. Natural selection may thus be the deciding factor in determining the permanency of orthogenetic variations.

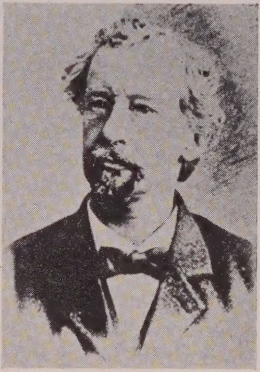

FIG. 388. — Hugo de Vries.

Theory of Mutation. Darwin did not emphasize the origin of variations, nor did Lamarck explain their origin at all satisfactorily. The mutationists, founded by Hugo de Vries of Holland (Fig. 388), believe that new species arise suddenly and that offspring appear with well-differentiated variations, not possessed by the parents or the parental line. The mutationist does not believe that natural selection really starts species. Natural selection controls the persistence of this and that mutation. The variations emphasized by Darwin were small and fluctuating. He believed in a gradual quantitative increase in these, generation after generation, by natural selection. But the mutationist claims that such variations are of no evolutionary significance, they get nowhere, they are like the endless rise and fall of the tide. Darwin described sudden distinct, discontinuous variations, but assigned no importance to them. He even described what is now thought to have been a mutation.

In 1791, in Massachusetts there appeared in a flock of a certain breed of sheep, a short-legged ram which was of a distinctively different type. This ram bred to females of the breed, from which he so suddenly appeared, produced offspring that were like him. Thus a new breed, the Ancon breed of sheep, was begun. Due to the short legs, these sheep could not jump fences. The breed was discontinued when the Merino with a better grade of wool was introduced. Bateson in England, in 1894, in " Materials for the Study of Variation," called attention to 886 cases of discontinuous variations. Discontinuous variations were called " sports " by Darwin, such distinctly different characters as a four-horned sheep or an eight-fingered man or a one-toe pig. But all discontinuous variations are not alone differences in numbers of parts. They may be differences along any line, as color, form and size.

The classic case of mutations is that described by Hugo de Vries of Amsterdam, in his book " Species and Varieties," published in 1904. This book gives an account of years of hard work. The rediscovery of Mendel's principles by De Vries, about 1900, during the period of his investigations, influenced him in his conclusion that evolution did not take place by the gradual accumulation of slight, fluctuating variations by natural selection, as Darwin had maintained, but by the sudden appearance of a *full-fledged elementary species.* His studies were made on a primrose of the generic name Oenothera. A certain species, *Oenothera lamarckiana,* was indigenous to America. It was taken to London about 1860 as a garden plant and was introduced in other places in Europe. It spread outside of gardens and De Vries found it growing wild in a potato patch a few miles from Amsterdam in 1886. He observed that it presented considerable variability. *Oenothera lamarckiana* is a large, bushy plant over four feet high with large, bright yellow flowers which open toward evening, hence the name evening primrose. Among them he observed different and distinct types. Wishing to study the matter he experimented further with them in the Botanical Gardens at Amsterdam. He transplanted some of the wild plants or gathered the seed for planting in his garden, and sowed the seeds which developed on the transplanted plants. In seven years he had grown and studied 54,343 plants; 837 of these belonged to new types, or *mutants.* He writes, " These various methods have led to the discovery of over a dozen new types never previously observed or described."

Among the wild Oenotheras he found two different types which he called *O. brevistylis,* because the style of the pistil was short, and *O. laevifolia,* because it had smooth leaves. He regarded these as *mutants.* In his gardens in those years of cultivation, he claims to have found seven other new elementary species all originating from self-fertilized seeds of *O. lamarckiana*. A systematist would regard them as distinct species. It has been suggested that possibly the results of natural hybridization of two or more wild species produced so-called new species which are merely different types of hybrids. Davis has crossed two wild American species and has produced a hybrid resembling *O. lamarckiana,* and this produces forms resembling the mutants of De Vries.

De Vries' work has been repeated and his conclusions confirmed. In 1899, a hornless Hereford appeared in Kansas. From this animal has arisen the hornless breed of Hereford cattle. Tailless cats, dogs and poultry are probably mutants, so also are hairless dogs, horses, cattle and mice.

T. H. Morgan and his co-workers, in their most careful investigation with the rapid-breeding fruit fly, Drosophila, have found hundreds of suddenly appearing new characters which they call *mutations*. Most of the mutants have a " lethal " characteristic and the animals showing these particular mutations die. Most of the experimentally produced mutations in fruit flies differ from each other in only one or two features, while ordinary wild species differ in many individual characters. And yet this is no real criticism, for if one new character could arise as a mutation, there is no reason why many should not do so. Morgan has pointed out features wherein the mutation theory escapes the criticism of the Darwinian theory of natural selection.

As mutants appear fully formed, there are no initial stages to account for. Useless structures appearing as mutations may persist if they are not detrimental to the continuance of the species. Also mutants may be better fitted to live in a new environment than the parental forms. This might lead to isolation which would prevent hybridization (and hence loss of the newly gained advantage) with the parental form. The mutant may differ " from the parent form in only a slight degree for each point, although all the points may be different" (De Vries). Moreover the characteristics acquired by mutation are inherited. This is the most important point necessary to explain evolution.

A certain amount of experimental work has thrown light on the origin of mutations. After obtaining a pure race of potato beetles (*Leptinotarsa decemlineata*), Tower subjected them to different conditions of temperature and humidity. The few offspring showed decidedly different characters and they bred true to these new characters, and Tower claimed them to be mutants. Gager exposed ovules of plants to radium rays which apparently changed the germ cells, for the plants were stunted and abnormal. Some of these continued for several generations. MacDougal injected cane sugar and zinc salts into the ovules of different plants and forms varying distinctly from the parental type developed. These also bred true for the few years that he continued the experiments. An attempt has been made to correlate the origin of mutations with the number and size of chromosomes. The typical number of chromosomes in *O. lamarckiana* is 14, but Gates has found 15, 20, 21, 22, 23, 27, 28, 29, 30, in some. In the fruit fly, Drosophila, Metz has found variations in the number of chromosomes even to a doubling of the number, but the quantity of chromatin remains the same.

Summary. Discovery of *pure lines* indicates that the best that selection can do is to isolate pure lines. Selection cannot change genes. Genes or determiners of heredity (*i.e.*, chromatin) have been shown to be possessed of great stability. Morgan cites evidence indicating that factors or genes are not variable. It is true that the production of the extremely valuable domestic plants and animals has involved selection. But it is now believed that other factors have been involved, which were unknown to the producers of these useful breeds. In many cases, the breeder has unconsciously been selecting a " pure line," a " genotype." Or again mutations have probably been chosen. Ears of corn are now grown which are larger and better than any that appear in a state of nature. Often mutations, that can be artificially preserved, would disappear in a state of nature. Luther Burbank made many new combinations by hybridization. He destroyed all progeny but the one that suited, even though the others ran into the thousands, and, as a rule, continued the new form by such methods as grafting. According to Morgan it is possible to form apparently new characters by combinations in hybridization. These can be preserved by following out the procedure indicated by Mendelian heredity as at present understood. If indifferent mutations arise, their future continuance is a matter of chance. If injurious mutations arise, they will disappear by natural selection. If beneficial mutations arise, they will tend to be preserved by natural selection. There is no evidence that natural selection determines the formation of favorable variations.

Professor Morgan says that "Evolution has taken place by the incorporation into the race of those mutations that are beneficial to the life and reproduction of the organism." Genetics is the science of origins. While it works specifically with individuals, at the same time its results throw light on the origin of species. Living things exhibit two great tendencies: first, to produce offspring like their parents in some respects but at the same time different in other respects. It is the preservation, accumulation and continued modification of the unlikenesses in racial lines which make for organic evolution. New combinations of genes as afforded by sexual reproduction would play a part in this. Any qualitative change in a chromosome would be a factor. Qualitative changes have been produced, as, for example, recent experiments in radiation. Müller appears to have produced mutations in Drosophila by means of extreme temperatures and X-rays. Cases have been found in which changes appear to have occurred and these are at present not understood. We have called attention to changes in chromosome numbers possessed by forms unlike their parents. Sometimes there is a multiplication of one of the chromosomes. We have already called attention to the effect of changes in the environment. Sexual reproduction, involving new combinations when paternal and maternal chromosomes fuse, will produce offspring different from either. This is the amphimixis of biparental marriage. We have already noted (page 336) how great a variety of combinations are possible in sexual reproduction.

Is it possible that mutations or the appearance of distinctly new variations have arisen by amphimixis? If this were the case, it would imply that the lowest Protozoa and Protophyta contained chromatin which was ancestral to all the present chromosomes of all organic forms and possessed all the factors out of which, by a process of sorting out, the present world of plants and animals has been evolved.

Bateson suggested such a fanciful proposition. Somehow one cannot sidetrack the ever-intrusive thought that the constant effect of new environmental conditions has had a great deal to do with evolution; but not in the direct way suggested by Lamarck. In a sense, water at one time was a mutation, so was carbon dioxide and urea and ammonia and other compounds. These combinations are so relatively simple that the physical scientist can experimentally reproduce the mutation. When more is known about the physics and chemistry of somatoplasm and germ plasm, so that we can produce mutations experimentally, then something will be really known about the origin of natural mutations or variations and the causes of organic evolution. This may not be so far distant. Morgan says: "The causes of mutations, that give rise to new characters, we do not know, although we have no reason for supposing that they are due to other than natural causes." Bateson, however, in speaking of the larger question of the causes of evolution pessimistically said: "The many converging lines of evidence point so clearly to the central fact of the origin of forms of life by an evolutionary process that we are compelled to accept this deduction, but as to almost all the essential features, whether of cause or mode, by which specific diversity has become what we perceive it to be, we have to confess an ignorance nearly total."

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CHAPTER XXVII

THE BIOLOGY OF MAN

Introduction. There are many references in the preceding pages to organisms which affect man. However, since man himself is a living organism, he also is a proper object for biological investigation. As a part of the great living world he may occupy a lofty seat in dominion over inanimate nature, over plants and over the lower animals, but he is nevertheless fiber of the living fabric of nature, and a product of ages of adaptation.

Classification. From a taxonomic point of view, he is without any doubt a Chordate, for a notochord, gill slits and a hollow dorsal nerve cord appear during the course of his embryonic development, just as they do in the life of a fish, a frog, a lizard, a hen and a cat. He has a jointed backbone and so is a Vertebrate; he has constant temperatured blood, hair and a diaphragm separating the body cavity into a thorax and an abdomen, and so is a Mammal. Man is a placental Mammal, because in the development of the embryo there is no great quantity of yolk present, and the old reptilian allantois and amnion are arranged to develop into a placenta. He is a Primate, for he has prehensile limbs, his thumb is opposable, his digits have flat nails, he has a collar bone or clavicle and his mammary glands are thoracic. Linnaeus proposed the word Primates to designate the first and highest group of animals. Although Primates such as the chimpanzee and gorilla have not been domesticated, as have the dog, elephant and horse, yet the relatively small amount of investigation so far given to the matter, indicates that the anthropoid apes are the most intelligent of all animals below man. It is the further development of the brain, and everything that this signifies, that places civilized man far in advance of other Primates. Chemical analysis of the body reveals the same chemical elements and compounds, organic and inorganic, as are found in other animals.

Embryology. A careful study of the *embryological development* of man begins with an egg cell, 135 μ in diameter, a microscopic speck of protoplasm, a typical cell with a nucleus. After fertilization, cleavage stages appear, then a blastula stage is developed, followed by a gastrula stage with ectoderm and endoderm and later mesoderm. A mouth forms by invagination. Other organs which develop are the notochord, the nerve cord, the gill slits, the fish-like heart, the cartilaginous skeleton of the shark, the allantois and amnion of reptile and bird. The heart changes from a two-chambered, to a three-chambered, and then to a four-chambered organ with right and left sides. One can see the lungs, liver, pancreas, pronephros, mesonephros, testis, ovary, Wolffian duct, Müllerian duct (oviduct) form as in other Vertebrates. In certain early stages it is difficult to decide to what class of Mammals this embryo belongs, then mammalian characteristics appear and later primate characteristics. So far as embryological observations go, man is plainly a Primate, a Mammal and a Vertebrate.

Histology. *Histological investigation* shows his skeletal muscle to be made up of muscle fiber units as in other Vertebrates, surprisingly like those of the Mammals and especially the Primates. Histological examination of the smooth muscle of the intestine shows that it is composed of smooth muscle cells as in the intestines of other Vertebrates and more especially Mammals. Similar epithelial cells are found in corresponding locations. Connective tissues such as bone, cartilage, fat, are similar; also the most specialized of all tissues, neurons, are similar. No different types of neurons are found in man than are found in other Mammals. Detailed histological studies of the various organs reveal the fact that liver, pancreas, kidney, testis and lung are all built on the same general histologic plan as the other Mammals. Microscopic resemblance is borne out by the searching powers of the microscope. *Physiological and pathological processes* are also similar. When, by experiment, causes of disease in lower animals are discovered and such diseases prevented or cured, this same knowledge can be applied to the same diseases in man and with the same result.

Comparative Anatomy. Galen (second century, A.D.), the most able anatomist of antiquity, taught for a while at Rome. He was not permitted to dissect human bodies, and was compelled to use bodies of lower animals in his demonstrations. Despite this, his errors were mostly in details, for in general outline, the anatomy of a dog or cat serves fairly well to illustrate human anatomy. When a monkey or, better still, a chimpanzee is available, the resemblance is still more striking. When compared, the skeletons of a man, chimpanzee, gorilla, cat, dog, deer and horse, part by part, and bone by bone, reveal differences, but what attracts attention most are the similarities in all these Mammals. Correlated with different forms of locomotion one notes differences in shoulder girdles and in the feet (especially the fingers) of all the above examples. Correlated with differences in food one finds differences in skull structure, teeth, etc. Correlated with differences in intelligence one finds differences in cranial capacities and brains. Due to differences in food one finds specialized stomachs in Herbivora, as compared with Carnivora or with Omnivora (man). But the general structure of the voice-box, larynx, trachea and lungs, oesophagus, stomach, intestine, heart, arteries, veins and capillaries, liver, gall bladder, bile duct, adrenal gland, general anatomy of the brain, spinal cord, cranial and spinal nerves, sympathetic nervous system, demonstrates without any questioning a similar groundwork behind the differences. When man is examined from any morphological, physiological, histological, embryological or chemical standpoint, the only rational conclusion is that the same agency that fashioned fish, frog, lizard, bird or other Mammal also fashioned man. The man-like or anthropoid apes, of all other animals, most closely resemble man. Man did not evolve from these apes, but both had a common ancestor.

The species, *Homo sapiens*, family Hominidae, shows in many details of gross and detailed structure close similarities with the Simiidae. Terrestrial life in the open, erect posture, and greater development of the brain have produced differences. Bipedal locomotion has changed the curvature of the spine, lengthened the legs, modified the opposable character of the great toe, freed the arms for a multiplicity of motions, increased the use of the thumb and made the hand a great instrument of use for attack and defense and for gathering and preparing food.

The human body exhibits many primitive characteristics. The radius and ulna are well developed, and many of the wrist bones are distinct. The fibula of the leg is quite large, and the foot is plantigrade. There are still five digits, and the number of phalanges is the same as the primitive number. The shoulder girdle retains the clavicle. The atlas supporting the skull is primitive. The teeth are simple and the premolars are simpler than the molars. The stomach is far simpler than that of the Ruminants and the vermiform appendix is far less specialized than in the Rodents. In many respects man is generalized in structure, but he also exhibits specialization, such as four curvatures of the spine at maturity and the basin-shaped pelvis aiding in the support of the viscera. The pelvis of anthropoid apes is flat as is that of human embryos. The fore-limbs are short. In the foot, the great toe is very rarely opposable, the shock-preventing arch has developed so that the axis of the foot runs along the inner side through the great toe, which is largest, the others having become smaller. The fusion of the two end phalanges of the fifth toe, in a number of cases, is interpreted as an indication of the progressive diminution of the outer toes and increase of the great toe. The hair scattered over the body usually disappears, and the skin is thus more sensitive. Skin pigment has disappeared in some races. There are thirty-two teeth as in the Simiidae, but they are relatively smaller, especially the canines. Tooth reduction is apparently taking place, as is evidenced by frequent lack of the second incisors and the third molars.

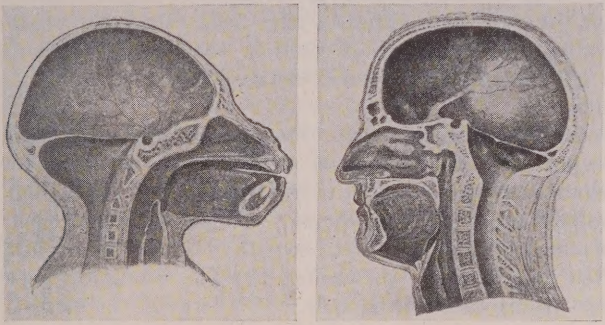


FIG. 389. — Comparison of brain case of ape with that of man. (Photo by American Museum of Natural History.)

The face is shorter and the facial angle tends to approach a right angle. The facial angle is obtained by drawing a line from the lower margin of the nasal aperture to the ear opening and another line from the forehead to the upper jaw. In the anthropoid apes this is an acute angle. In size the human brain is, on the whole, relatively larger than that of any other Vertebrate. Especially prominent is the large size of the cerebrum in proportion to other parts (Fig. 389). The cerebellum, though much smaller than the cerebral hemispheres, is relatively large also. The cerebrum covers the cerebellum above and the cortex of the cerebrum is increased in area by a complicated system of convolutions and fissures. Especially well developed are the frontal lobes, supposed to be the physical seat of the higher intellectual powers.

Articulate speech is a special distinguishing characteristic also. This has its physical basis in the greater development of certain regions in the brain. Interchange of experiences between individuals is thus possible. Two heads are better than one, which leads to the formation of generalizations, abstract thought, and hence reason. It is impossible in this synopsis to develop further the very evident relation between development of language and civilization. A wide gulf separates man from the Anthropoids and hence from the rest of animal creation. Nevertheless underneath that gulf extends the connecting ocean floor of fundamental resemblances.

Pre-human Characteristics. Most persons have the following characteristics: (1) hair which runs from the shoulder toward the elbow and from the wrist to the elbow. This is also found in anthropoid apes. Hair is oily and, thus placed, would shed rain from an animal crouching in a tree with his arms over his head, as is often the posture of the orang. (2) The vermiform appendix is short in man and in the apes. It is large in the embryo but growth ceases and it becomes relatively small. It is smaller in some persons than in others. Apparently the body functions perfectly without it. In certain herbivorous animals, such as the rabbit, it is large and functional. (3) Dogs and other animals have well-developed muscles for erecting the ears and the hair. These muscles are present, but are small, and usually do not function *in most persons.* (4) In the inner corner of the eye is a third little fold called the *Plica semilunaris.* This is all that is left of the eyelid or nictitating membrane of the eye of some Mammals and Birds. (5) The pineal body rising from the dorsal surface of the diencephalon is a mere remnant in man. In certain Reptiles it is connected with a median eye-like structure in the middle of the head. (6) In most Mammals the incisor teeth in the upper jaw are borne on a separate bone called the premaxillary. There usually is no sign of such a separate bone in either men or the chimpanzee, but separate premaxillary bones in man have been found. (7) The dorsal and front part of the brain in most Mammals is protected by a *pair* of frontal bones. In man this is single in the vast majority of cases, but paired frontal bones sometimes occur. (8) In rare cases a gill slit remains at maturity. Some vestigial structures appear during development, only to disappear later. It has been stated that the first gill slit (or spiracle of Elasmobranchs) is normally retained as the Eustachian tube of the ear. Cases have been found in which more than one gill slit was developed into an ear chamber, and extra external ears appeared. (9) The tail of the adult is reduced to a mere vestige. When it fails to discontinue development, human infants appear with tails. In embryos it is present, and even has muscles as in tailed forms. (10) Up to the sixth month of prenatal growth the body develops a coat of long black hair called the lanugo. This disappears before birth. Sometimes it persists, animal-like, in the adult. The embryos of hairless Mammals such as the elephant and whales also have the foetal lanugo.

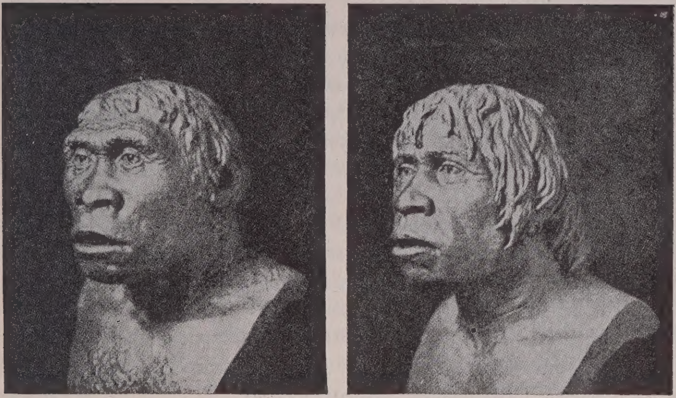
(11) It has been observed that newly-born babes have the remarkable power of supporting the weight of the body by clinging to some object, like a stick. It is interpreted as being a vestige from the old arboreal days of the race. The human body has imperfections wrought by natural experiment during the ages. Almost any good oculist could give plans and specifications for a better all-round standard eye than man possesses. This is also true of other organs such as the ear, teeth, lungs, stomach, colon and heart. As one gazes on the works of ancient artists and sculptors, one is led to conclude that the race of men must have been perfect in those days. They depicted strong-limbed, perfectly proportioned men, and women of beautiful form. Such conclusions are erroneous. Those great artists did not picture the average human form as it then existed, but they represented the perfect type as they wished to see it. In spite of the fact that modern science was not present to save for reproduction the weaklings, it is very probable that the lame, the halt and the blind then existed.

Palaeontology. The science of Palaeontology, with the evidences collected, indicate that Carnivora and Primates arose from an insectivorous-like form, very early in Cenozoic time; that the Primates appeared in the early Eocene Period in that portion of the world as far south of the north pole as would now include Asia. Fossil Primates have been found in America and Europe during the Oligocene. They reappear in Europe in the Lower Miocene. They were compelled to migrate, due to the southerly progress of cold which killed the forests. Their continued presence in Southern Asia, Africa and South America indicates evolution in these localities after this southward migration.

There are several reasons for the belief that the form, ancestral to man, changed from an arboreal habitat to a terrestrial one in Central Asia, somewhere between Miocene and early Pliocene time, and that the pre-human line emerged during the Pliocene. Change from an arboreal to a terrestrial life involved erect posture, which freed hands to execute thought plans. The necessity for finding food developed the hunting habit. Later, the use of clothing and a great variety of food meant ability to range far and wide and the further development of social organizations for the mutual benefit of individuals.

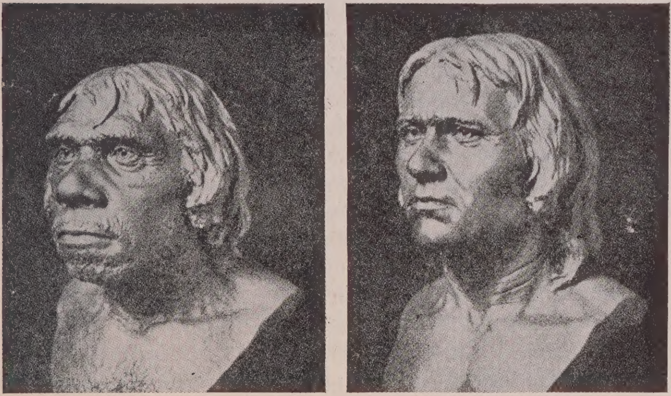
Fossil remains of ancient man are very rare. What is regarded as the partial remains of a primitive man was found in Java in 1894. The skull cap and two upper molar teeth were recovered, and a short distance away a femur bone. Careful comparisons indicate that the animal was rather prehuman than ape-like. The skull capacity was two thirds of the average human skull. The forehead was low and flat, with prominent supraorbital ridges. The brain was therefore small and the frontal lobes especially so. The teeth, though primitive, were more human than ape-like. The body height was probably nearly as great as that of living men. Fossil animals found with it place it between Upper Pliocene and Lower Pleistocene. This is known as the Java ape-man or *Pithecanthropus erectus* (Fig. 390).

A mere fragment of what is regarded as the oldest European race, of which there is any evidence, was discovered seventy-nine feet below the surface in river sands near Heidelberg, Germany, in 1907. This fossil was a perfect lower jaw with teeth. It used to be said of Cuvier, the great French comparative anatomist and anti-evolutionist, that he could examine a single bone and identify the animal of which it had been a part. This Heidelberg jaw has been studied most carefully by even greater experts than Cuvier, and it is regarded as belonging to a higher race than Pithecanthropus. From other fossil remains found with it, such as those of primitive elephants, horses, lions, it is believed to have existed in the second interglacial age. There are also indications that



JAVA MAN
Pithecanthropus erectus.

PILTDOWN MAN
Eoanthropus dawsoni.



NEANDERTHAL MAN
Homo neanderthalensis.

CRÔ-MAGNON MAN
Homo sapiens.

Fig. 390. — Heads modelled by Professor J. H. McGregor, based on his exhaustive studies of prehuman and ancient human types. These types probably represent divergent lines. (From original models. Courtesy of Dr. McGregor.)

these men selected and used shaped stones as tools in their daily occupations.

What is known as the Piltdown or dawn man or Eoanthropus was discovered in Sussex, England, in 1912. Portions of a brain case, a canine tooth and part of the lower jaw were found. The tooth and the jaw are thought by some to have belonged to a chimpanzee. The skull remnants indicate a *human type.* It is improbable that two different parts of such different forms as man and ape would occur together.

Very recently (December 1929) in an excavation made near Peking, China, there was found the skull of a primitive human (probably female) which has been named Sinanthropus Pekinensis. A complete study will not be possible until it has been entirely removed from its stony matrix. Other remains such as teeth, a jaw and skull fragments have been found in the same excavations and other important discoveries are expected. The cranium of the Peking Man is quite perfect and altogether it is a more valuable find than the fragments which represent the Heidelberg and Piltdown *men.* The Peking Man probably lived in the early Pleistocene.

In 1856 a skeleton of a primitive man was found in a limestone cavern near Düsseldorf, Prussia. It was partly destroyed by its discoverers. Later similar specimens were found at Spy in Belgium, and in France. It is claimed that they evidence the existence of a primitive race known as the Neanderthal Men : short in height, strongly built, with prominent overhanging brows, retreating forehead, large and human-like brain, massive jaws, receding chin, large hands, thumb not greatly opposable, short lower leg. They were probably not erect and walked with a shuffling gait. This Neanderthal race lived in Europe from the third interglacial stage, through the fourth glacial period. They were unprogressive, but had at least developed well-wrought flint tools and ornaments, which they buried with their dead.

In Wales and France skeletons of an ancient type were excavated years ago, but were not given close study. Five more skeletons similar in character were found in Crô-magnon France, in 1868. These remains have established the existence of the Crô-magnon race of men. It is described as having been a magnificent race — superior to many existing today. The men were over six feet in height, probably taller than the tallest living races. They had large brains, high foreheads and a facial angle as high as modern men, wide short faces, prominent cheek bones, strong jaws, prominent chins, long legs and were, therefore, swiftly moving. Their burial customs indicate belief in immortality. This race finally declined, leaving but few survivors. Some of these live in France today. On the walls of caves in France and in Spain, Crô-magnon artists made drawings of themselves, of their tools and of the animals of their day. Fortunately these drawings, preserved for thousands of years, have again come to the view of the descendants of other races of men, who migrated to Europe from Asia. The repopulation of Europe probably took place in the upper Paleolithic.

More Recent Evidences of Human Antiquity. There are many evidences of human antiquity. How did the ancestors of the American Indian reach this continent? It is unlikely that they could have crossed great sea-distances in the little boats known to ancient men. They may have wandered by way of Bering Strait. The discovery of ancient cities in South America, which flourished long before the Christian Era, indicate the relatively great antiquity of native Americans. The North American Red men, the Eskimos, the superbly physically perfect peoples of some of the South Sea Islands present other problems. No records exist that give information of their origin. This distribution to the uttermost parts of the habitable globe and subsequent establishment there in the absence of easy methods of transportation must have taken great periods of time. There are no evidences of great sudden environmental changes which would have brought this about. The production of different races must have taken a long time. Egyptian paintings, several thousand years old, indicate that certain races had even then been long established. The development of intelligence was slow also. Babylonian inscriptions, twice as old as the times of Abraham, indicate that civilized nations had existed thousands of years before. The paleontological evidence, while meager, yet corroborates the other evidence.

The Power of Intelligence. Due to the development of the brain and the acquisition of intelligence, man with his relatively poor eyesight extends his vision by means of invention and can see microscopically and macroscopically infinitely more and better than any other animal. With his limited sense of hearing he can also hear farther than any other animal. He can talk across oceans and around the world. Though heavy limbed, he can outrace the swiftest antelope; terrestrial in habit, he can explore the depths of the ocean like the whale and lacking wings, he can soar far and high, better than any bird. Due to his great intelligence he can in his mind repopulate the stony piles of ancient cities and reconstruct their streets, re-establish their commerce, and can thus view again, centuries later, their birth, their development and decline. He is the most highly adapted of all living things. He has wrenched secrets from Nature, and her forces are his servants. He knows Nature and he knows himself, a little.

But these accomplishments are not true of all men. Races of men exist on the globe today, as they have existed for ages, and are but little higher than other animals. Nor have *all* men who live in civilized communities accomplished great things. Many even now spend their lives in a mere existence but little above that of the animals. The lordship of man has been accomplished by those who were born unusually strong, courageous and daring, by the adventurous and by those endowed with unusual intelligence. Progress has always depended upon leaders. Variation among men is a primary biological law, for they are certainly not created equal. One is born with one talent, one with ten, one with a thousand. The creative genius, moreover, is not necessarily inspired to accomplishment by expected fame or fortune, but often because of an inborn urge for expression. Such men represent a fortuitous combination of genes and fortunate postnatal circumstances.

Civilized man is possibly not as strong muscularly, nor as keen of sight or hearing, nor so adept with his hand, as his forefathers were. And this is due to the appearance of his inventions which so marvelously complement or excel his poor faculties, and lead also to a certain amount of disuse. There is danger in this and it should not be forgotten that an overspecialization in a changing world has caused the extinction of more than the Dinosaurs.

Euthenics. Euthenics refers to agencies undertaken for the improvement of social conditions such as better water supply, better air, better habitations, better food, more wages, more rest and recreation. Medicine is changing from an art to a science, an achievement which is the result of biological investigations. Prevention of yellow fever, malaria, typhoid, diphtheria, smallpox and scarlet fever are instances of victories over disease organisms. The saving of man's domesticated plants and animals from destructive parasites is another sort of biological work, all in the general direction of human Euthenics. Agricultural science has developed largely by the same agency, namely, biology. In all of this work use has been made of physics and chemistry, which are fundamental to biology. Compare the England of today with the picture drawn by Mark Twain in " A Connecticut Yankee at King Arthur's Court " and note the differences that have taken place in a few hundred years. Mark Twain was not primarily interested in telling a funny story, when he visualized the state of English society in the days of King Arthur.

It has been claimed that the saving of lives by improved euthenical conditions (and this includes not only the work of all philanthropies, but of all medical science) works to the detriment of the race and that the general effect is the survival of the unfit, the propagation of those who will become a burden and a menace to society. One answer to this argument is that countries which stand highest in euthenical progress should be compared with countries where practically no attempt is made to improve conditions, but where natural selection is left comparatively free to eliminate the unfit. Compare, for example, the people of the British Isles with the natives of India; compare Americans in general with the great population of China. One cannot escape from the conclusion that euthenical progress is a sound policy and is good biology. Oftentimes charity and philanthropy take a distressing situation and clear it up. As the result of a helping hand, helplessness disappears, and even productivity is brought about. Parents, poverty stricken through disease or other misfortune, die and leave children who, rescued by charity, grow up into able and valuable citizens. Death is often due to maladjustment of just one part of the living machine. The person involved may be of great potential value to society. Medical science corrects this abnormal condition. A lifetime of usefulness is the profit gained by society.

The public is constantly being informed of the discoveries of medical science. Information regarding the safeguarding of health is given, and, on the whole, men are disposed even from a selfish standpoint to profit by it. Society is the gainer, due to added years of usefulness. Human disease is a great tax upon resources of society. It is a burden that rests upon the shoulders of the well. Countries that carry such a burden also lead the world in accomplishments. Somehow, sadly deficient as it is, modern euthenical policy in civilized countries helps to conserve intelligence and prolong the period of productiveness. The effect of saving the weak often means that many of these weak are made strong.

What is a perfect organism? Is it not a body perfectly adapted? Is not medical science above all things taking a hand in this very matter, and aiding in adaptation? Is it not pointing out a thousand kinds of imperfect adaptations, and constantly correcting these? Is it not, after all, a case of intelligence assuming control and directing natural forces?

Eugenics. The objector to charitable and philanthropical aspects of the present-day euthenic policy suggests another program, namely, Eugenics. The word literally means "*well born.*" It is more of a propaganda than a science. It is a position that an intelligent person must take after ascertaining the facts of human heredity or genetics. The investigation of human inheritance reveals the perpetuation of many distressing conditions in man. Not only are defects, abnormalities and weaknesses at times perpetuated in increasing numbers, but this unintelligent policy results in burdens that must be paid for by society at large.

The eugenist rightly claims that far more care and scientific common sense is employed in raising good vegetables and domestic animals than men. For ages man has deliberately chosen the best for parents of his domestic animals, in his endeavor to produce a desired breed. He is only too careful of his pedigreed stock. But where human breeding is concerned, this has been allowed to take its course. The reason probably is that no man considered himself warranted in interfering in a matter of individual liberty, and it is certainly true that men have fought and died for that precious possession — human freedom. Undoubtedly the discoveries made and to be made in the study of human heredity will lead to a curbing of freedom in marriage. What facts indicate that this position is warranted? Certain common human defects have been proved to be dominant Mendelian characters, such as a cataract, an opacity in the transparent part of the eye. In one form it develops in middle life. Such persons become blind. In a study made of 304 families in which this defect occurred, it was found that over half of the thousand children inherited the defect, although the defective parent mated with a normal person. Again, studies of inheritance of certain types of deafness and deafmutism showed these to be inherited by children. In all of these cases the defects act as handicaps to a normal life. Not only do they involve suffering for the possessors of these characters, but a tax upon society. One of the great discoveries of medical science is that of prophylaxis, which means the *prevention* of disease. Nevertheless, all dominant defects could be largely eliminated from human society by preventing such persons from having children.

Feeble-minded persons, as a rule, are supported in public institutions. The care taken of them is a by-product of modern euthenical policy. Goddard, in charge of the State Home for the Feeble-Minded at Vineland, New Jersey, collected data with regard to the offspring of 122 marriages of the congenitally feeble-minded. They had 482 children, of whom 476 were feeble-minded. He collected data with regard to the offspring of parents, one of whom was normal and the other feeble-minded. From 122 pairs of such parents came 371 children, 193 of whom were feeble-minded and 178 normal. Goddard's studies indicate that feeble-mindedness behaves like a Mendelian recessive. A feeble-minded little girl, an inmate of this splendid institution, had a feeble-minded brother. Both parents were feeble-minded. Goddard looked up this family history. Among the relatives of the same generation as the child he found 16 feeble-minded out of a total of 25, *i.e.*, 64 per cent were feeble-minded; of the parental generation 21 feeble-minded out of a total of 25 persons, or 84 per cent; and of the grandparent generation 6 feeble-minded out of a total of 8, or 75 per cent.

One of the causes of feeble-mindedness is syphilis. Alcoholic parents also have more feeble-minded children than non-alcoholic parents. Abnormality will continue to appear as long as there are parents who are alcoholic and syphilitic. In the study of physiology presented here, it was pointed out that a cretin is an idiotic or feeble-minded, undeveloped individual, a condition brought about by the failure of the thyroid gland to develop. Some years ago 60 per cent of the population of a certain locality were cretins. They were allowed to intermarry and the offspring were cretins. Finally a law was passed forbidding marriage of cretin with cretin. Today but few cases remain. This is an example of the effects of a eugenic program. Studies of the pedigrees of inmates of insane asylums, who are usually committed after middle life and so after some years of married life, indicate the inheritance of many forms of nervous instability or abnormality in their offspring.

One of the best illustrations of the perpetuation of the unfit is shown by the pedigree of the Jukes family of New York State. In five generations this family numbered about 1200 people and was distinctively an American family. Its history is known back to 1720. Kellicott says: " Of these 1200 idle, ignorant, lewd, vicious, pauper, diseased, imbecile, insane and criminal specimens of humanity, about 300 died in infancy. Of the remaining, 310 were professional paupers in almshouses, a total of 2300 years (at whose expense?); 440 were physically wrecked by their own diseased wickedness; more than half of the women were prostitutes; 130 were convicted criminals; 60 were habitual thieves; 7 were murderers. They have cost the state over a million and a quarter dollars, and the cost is still going on."

On the other hand, the history of the famous Edwards family of New England is just as bright as the Jukes' case is dark. Jonathan Edwards was a clergyman in the early days of New England. He was a man of unusual ability. In 1900, 1394 of his descendants had been identified. Of these 299 were college graduates; 13 were college presidents; 65 were college professors; 60 were physicians; 100 or more clergymen; 75 were officers in the army or navy; 60 were prominent authors and writers; 100 were lawyers; 30 were judges; 3 were U. S. Senators, one was a Vice-President of the United States, many were eminent in law, theology, medicine, business, education and public service. The general contribution to social progress made by this family has been decidedly positive and constructive. The general contribution of such as the Jukes family has been decidedly negative and destructive.

Darwin summed up the general attitude of society in these words, " Except in the case of man himself — hardly anyone is so ignorant as to allow his worst animals to breed."

Such agencies as the Galton Laboratory for Eugenics in England and the Eugenics Record Office at Cold Spring Harbor, N. Y., and the active work of Eugenics associations, may lead the way to a correction of these ills. A wisely informed public can throw the weight of public opinion in the right direction. Not one iota of thoughtfulness and kindly treatment of the unfortunate should be surrendered from the present euthenical policy, for the net gain to society is greater than all the loss. But practical eugenics can eliminate most of the cost of euthenics.

An attempt at better immigration laws has been made. Some states now have eugenic marriage laws. But who is genetically fit? The animal breeder may have a pedigree of his breeding stock for generations back, but where can one go to get such very important information regarding human pedigrees? How many persons know anything about their great-great grandparents? The Eugenics Record Office is prepared to give advice concerning contemplated marriages but it could give better advice if it had a complete record of the family lines concerned. The state would do well to add a record of citizenship to the mere record of birth, marriage and death. Eugenics, now not at all popular, will be a matter of state policy. States will internationally discover that war is a most dysgenic method of settling disputes. War destroys the eugenically fit.

The marriage of the genetically fit should result in a controlled selection of offspring. Unrestricted birth rate, disproportionate to the means of support, means overcrowding, misery and the burden of charitable euthenical measures. In the present state of ignorance concerning human inheritance we are compelled to use euthenical methods to correct the ills of human society. It is a lack of insight to view capitalism as the sole cause of all human misery. Usually capital means industrial activity. Human misery may be due to poor protoplasm as well as to lack of employment or to poor wages.

It is part of the eugenic program to ask the genetically fit to produce, care for and train a representative number of offspring. During the last half century or so there has been a decline in the birth rate in most civilized countries. Large families are not the rule among the wealthy or well educated and this policy is extending to other groups. Unrestricted production of offspring by the irresponsible, the improvident and those dependent on charity, because they are on the whole unfit, is a dysgenic phenomenon. Historians have not always recognized the part played by insufficient food supplies, large populations and starvation as causes of war.

Dr. Stanley P. Davies in his recent book "Social Control of the Mentally Deficient," states that there has been a recession from the early conclusion that feeble-mindedness acted as a single recessive Mendelian unit character as was first claimed. Feeble-mindedness and probably other types of personality involve various complexes of traits and are not as simple affairs as first claimed.

Idiocy is now regarded as being due to disease or injury of the central nervous system or endocrine organs. The parents of mentally defective children in many cases are normal-minded. Individuals that are *feeble-minded by heredity* are not so prolific as has been claimed, — in fact there is a tendency for their germ plasm to die out. Dr. Davies' account of the splendid constructive work in socialization of the mentally deficient who are now trained in institutional farm colonies, for example, demonstrates the great value to society of this sort of euthenical work. It has long been felt that mental defectives are almost certain to be potential criminals. This is not true nor is it true that criminals are always mental defectives. Normal parents *may* have socially unfit children. Whether feeble-mindedness is a Mendelian trait or not, it yet remains advisable to discourage or prevent offspring production by abnormal personalities.

The state is maintained by the socially fit, and for the self protection and happiness of its members the state must continue to extend the policy of ever greater control of the socially unfit. In this work, the assay of personalities will include the part played by heredity *and* environment in determining what makes that personality. The psychiatrist has need of all knowledge bearing on his problems — including but not limited to the knowledge furnished by genetics.

Human Activities and Biology. It is surprising to note that the great mass of the world's population is engaged primarily in making it possible for other human beings to function biologically, *i.e.*, to continue to exist. This is the principal business of most people. It is not done in a spirit of altruism but is a matter of biological selfishness, namely, the necessity of self-preservation. It is quite surprising that most people do not realize this.

The activities of the potato plant, the wheat plant and the apple tree, so far as these plants are concerned, have no reference to man. The Amoeba, Hydra, Earthworm, Frog and other unsocial animals secure directly from their environment their necessities of life. The work of the early pioneers, more or less isolated from human neighbors, was, after all, somewhat similar.

But the development of civilized communities has meant a departure from primitive ways. Society is composed of a host of specialists, most of whom are engaged in particular processes that have to do with making it possible for other members of the community to continue as living biological organisms. The primitive organism secures its carbohydrate food directly from nature. Think of all the different kinds of workmen whose labors furnish us with bread! Horses, tractors, factories, mines, steel works, railroads, plant breeders, universities, laboratories, legislatures, farmers, warehouse men, salesmen, millwrights, mill hands, geologists, chemists, bakers, retailers, etc. We could extend this analysis to problems concerned in temperature regulation, which include clothing and the building and heating of houses; problems of water supply and problems having to do with excretion, such as sewage systems.

A biological basis should be considered in the study of many social problems. After all, the state or nation is but a group of a particular kind of living organisms associated for mutual benefit and the success of the state depends basically at least on the success with which every man in the state functions biologically. Widespread lack of food in a state is a menace to the continuation of that organization. Man has found great advantages in social organization, which is an outgrowth of the more primitive solitary individual existence. In taking up group living, the individual always has to give up a certain freedom of action which belongs to the solitary life. In spite of this newer social interrelationship, the old first law of self-preservation remains and is at times in conflict with later social responsibilities. Most men are engaged in the special tasks referred to, on account of an inward urge toward self-preservation. Man has learned that on the whole he is much better off in the new way of living. A great complicated and more or less integrated sort of organism has blundered its way onward through the ages. So intricate has this social organism become, that it is quite impossible to conceive of civilized men apart from such a mode of living. Today thieving and murder are examples of the continual outcropping of the old order of things. The criminal is one born without asking to be born into an order of things to which he is not adjusted.

Are there evidences of human evolution? Is man static or is he deteriorating? There are some who claim to see in present-day life plenty of evidence of retrogression. Is the human race moving toward any goal? Is the brain of man capable of continuing to maintain order in a world of constantly increasing complicated contacts between alien peoples? Can he maintain mental poise necessary for the continued operation of the ever-growing giant mechanisms he creates? Can he continue to control the orderly liberation of the ever-increasing stores of kinetic energy he develops? Man certainly differs from the lower animals in that he has a greater mental equipment for determining his goal and thus controlling his evolution. But these questions transcend what is ordinarily referred to as biological science and belong rather to the realm of social philosophy.

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APPENDIX A[1]

CLASSIFICATION OF PLANTS

Phylum — Thallophyta.
- Sub-phylum I — Algae.
  - Class 1 — Cyanophyceae (Blue-green Algae, 1200 species), Fission Algae.
    - Examples — Gleocapsa, Nostoc, Oscillatoria, Anabaena, Rivularia, Trichodesmium (Red Sea).
  - Class 2 — Chlorophyceae (Green Algae, 9000 species), Unicellular-green Algae, Desmids, Diatoms, Confervas, Pond Scums, Sea Lettuce, Tubular Algae, Stoneworts.
    - Examples — Pleurococcus, Sphaerella, Chlamydomonas, Gonium, Ulothrix, Ulva, Oedogonium, Cladophora, Spirogyra, Cosmarium, Navicula, Vaucheria, Chara.
  - Class 3 — Phaeophyceae (Brown Algae, 1000 species), Kelps and Rockweeds.
    - Examples — Ascophyllum, Fucus, Ectocarpus, Laminaria, Macrocystis, Postelsia, Sargassum.
  - Class 4 — Rhodophyceae (Red Algae, 3000 species).
    - Examples — Chondrus, Nemalion, Batrachospermum, Callithamnion, Dasya, Polysiphonia, Rhabdonia.
- Sub-phylum II — Fungi.
  - Class 1 — Schizomycetes (Bacteria, 1400 species).
    - Examples — Bacillus vulgaris, Bacillus typhi, Vibrio, Spirillum.
  - Class 2 — Myxomycetes (Slime Molds, 400 species), Slime Fungi, Fungus-animals.
    - Examples — Aethalium, Fuligo.
  - Class 3 — Phycomycetes (Alga-like Fungi, 330 species), Blights, Mildews, True Molds.
    - Examples — Rhizopus, Mucor, Saprolegnia, Albugo, Phytophthera.
  - Class 4 — Ascomycetes (Sac Fungi, 20,000 species), Black Fungi, Mildews, Yeasts, Blue and Green Molds, Lichens.
    - Examples — Penicillium, Aspergillus, Peziza, Morchella, Claviceps, Physcia, Cladonia, Usnea, Saccharomyces.

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[1] Several groups of organisms were omitted from the discussion in the text.

Class 5 — Basidiomycetes (Basidia Fungi, 20,000 species), Smuts, Rusts, Toadstools, Puff Balls, Mushrooms.
  Examples — Ustilago, Puccinia, Clavaria, Boletus, Hydnum, Agaricus, Coprinus, Amanita, Geaster.

Phylum — Bryophyta, 16,000 species.
  Class 1 — Hepaticae (Liverworts).
    Examples — Ricciocarpus, Marchantia, Porella, Anthoceros.
  Class 2 — Musci (True Mosses), True Mosses and Peat Mosses.
    Examples — Funaria, Bryum, Polytrichum, Sphagnum.

Phylum — Pteridophyta, 4500 species.
  Class 1 — Filicineae (Ferns).
    Examples — Aspidium, Pteris, Dicksonia, Osmunda, Onoclea, Nephrolepis, Gleichenia, Polypodium, Marsilia, Ophioglossum, Botrychium.
  Class 2 — Lycopodineae (Club Mosses).
    Examples — Lycopodium, Selaginella, Isoetes, Lepidodendrum.
  Class 3 — Equisetineae (Horsetails).
    Examples — Equisetum, Calamites.

Phylum — Spermatophyta.
  Class 1 — Gymnospermae (Gymnosperms), 500 species.
    Order 1 — Cycadales — (Cycads).
      Examples — Cycas, Zamia.
    Order 2 — Coniferales (Conifers).
      Examples — Pine, Fir, Spruce, Hemlock, Yew, Cedar, Cypress, Redwood, Larch, Juniper, Arbor Vitae.
  Class 2 — Angiospermae.
    Sub-class 1 — Dicotyledoneae, 100,000 species.
      Order 1 — Salicales — Willows.
      Order 2 — Juglandales — Walnuts, Hickories.
      Order 3 — Urticales — Elm, Fig.
      Order 4 — Rosales — Roses, Apple, Pear, Plum, Peach, Currant, Strawberry, Cherry, Beans, Peas.
      Order 5 — Sapindales — Maples.
      Order 6 — Opuntales — Cactus.
      Order 7 — Tubiflorae — Sweet Potato, Mint, Tobacco, Tomato, Potato.
      Order 8[1] — Campanulales — Squash, Pumpkin, Cucumber, Melon.
    Sub-class 2 — Monocotyledoneae (Monocotyledons), 30,000 species.
      Order 1 — Naidales — Water Plants.
      Order 2 — Graminales — Grasses, Corn, Wheat.

[1] Other orders are omitted.

Order 3 — Palmales — Palms.
Order 4 — Liliales — Lily, Asparagus, Iris, Tulip, Narcissus, Hyacinth.
Order 5 — Scitaminales — Banana, Canna.
Order 6[1] — Orchidales — Orchids.

CLASSIFICATION OF ANIMALS

Phylum — Protozoa. (One-celled animals.) About 10,000 species.
  Class 1 — Sarcodina. (Locomotion by means of pseudopodia.)
    Examples — Amoeba, Entamoeba, Difflugia, Arcella, Globigerina, Actinophrys, Thallasicola.
  Class 2 — Mastigophora. (Locomotion by means of flagella.)
    Examples — Spirochaeta, Treponema, Trypanosoma, Euglena, Synura, Pandorina, Volvox, Noctiluca.
  Class 3 — Infusoria. (Locomotion by means of cilia.)
    Examples — Paramoecium, Stentor, Stylonichia, Vorticella, Oxytricha, Euplotes, Didinium.
  Class 4 — Sporozoa. (Parasitic.)
    Examples — Porospora, Gregarina, Monocystis, Plasmodium.
METAZOA. (Many-celled animals; see the following Phyla.)
Phylum — Porifera. (Pore-bearing animals — Diploblastic and without intestinal cavity. The Sponges.) About 2500 species.
  Class 1 — Calcarea. (Simple sponges.)
    Examples — Grantia, Leucosolenia.
  Class 2 — Hexactinellida. (Glass sponges.)
    Examples — Euplectella, Hyalonema.
  Class 3 — Demospongiae. (Large, compound sponges, skeleton with spongin.)
    Examples — Euspongia, Chalina, Cliona, Tethya.
Phylum — Coelenterata. (Diploblastic with intestinal cavity.) About 4300 species.
  Class 1 — Hydrozoa. (Asexual hydroids with sexual medusoid stage.)
    Examples — Hydra, Pennaria, Campanularia, Obelia, Gonionemus, Physalia.
  Class 2 — Scyphozoa. (Larger Jellyfish, medusoid stage conspicuous.)
    Examples — Aurelia, Cyanea.
  Class 3 — Actinozoa. (Corals and Sea-anemones.)
    Examples — Corallium, Astrangia, Meandrina, Fungia, Metridium, Sagartia, Pennatula.
  Class 4 — Ctenophora. (Comb-bearing animals — Comb jellies.)
    Examples — Mnemiopsis, Beroe.

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[1] Other orders are omitted.

Phylum — Platyhelminthes. (Triploblastic — No Coelome. One opening serves as Mouth and Anus. Broad intestinal worms — flatworms.) About 4600 species.
  Class 1 — Turbellaria. (Small free-living flatworms.)
    Examples — Planaria, Bdelloura.
  Class 2 — Trematoda. (Flukes — parasitic.)
    Examples — Distomum.
  Class 3 — Cestoda. (Tapeworms.)
    Examples — Taenia, Crossobothrium.
  Class 4 — Nemertea. (Long, contractile, free-living flatworms.)
    Example — Cerebratulus.

Phylum — Nemathelminthes. (Triploblastic — Coelome doubtful. Mouth and anus. Thread worms.) About 1500 species. (Cobb estimates many thousand species.)
  Class 1 — Nematoda. (Round worms.)
    Examples — Filaria, Trichinella, Ascaris, Necator, Syngamus.
  Class 2 — Gordiacea. (Hair worms.)
    Example — Gordius.
  Class 3 — Acanthocephala. (Spiny-headed worms.)
    Example — Echinorhyncus.
  Class 4 — Chaetognatha. (Bristle-headed worms.)
    Example — Sagitta, the arrow worm.

Phylum — Trochelminthes. (Wheel worms, Wheel animalcules.)
  Class — Rotifera.
    Example — Rotifers.

Phylum — Molluscoidea. (Mollusk-like animals.)
  Class — Polyzoa. (Moss animals.)
    Example — Bugula.
  Class — Brachiopoda. (Arm-foot.)
    Example — Lingula.
    (Modern brachiopods are survivors of a once very numerous and varied group. Lingula appears to resemble closely similar forms found in the Silurian Period.)

Phylum — Echinodermata. (Spiny-skinned animals.) About 4000 species.
  Class 1 — Crinoidea. (Feather stars, sea-lilies.)
    Examples — Pentacrinus, Antedon.
  Class 2 — Asteroidea. (Starfishes.)
    Examples — Asterias, Solaster, Asterina, Ctenodiscus.
  Class 3 — Ophiuroidea. (Brittle stars, snake-stars.)
    Examples — Ophiopholis, Ophioderma, Gorgonocephalus.
  Class 4 — Echinoidea. (Sea-urchins, cake-urchins, sand-dollars.)

Examples — Arbacia, Strongylocentrotus, Echinarachnius, Clypeaster.

Class 5 — Holothuroidea. (Sea-cucumbers.)

Examples — Cucumaria, Thyone, Leptosynapta.

Phylum — Annelida or Annulata. (Segmented worms.) About 4500 species.

Class 1 — Archiannelida. (Primitive annelids.)

Example — Polygordius.

Class 2 — Chaetopoda. (Bristle-footed annelids.)

Order 1 — Polychaeta. (Many setae.)

Examples — Aphrodite, Syllis, Nereis, Chaetopterus, Cirratulus, Amphitrite, Arenicola, Hydroides.

Order 2 — Oligochaeta. (Few setae.)

Examples — Lumbricus, Allolobophora, Tubifex.

Class 3 — Hirudinea. (Leeches.)

Example — Hirudo.

Phylum — Mollusca. (Soft animals.) About 60,000 species.

Class 1 — Amphineura. (Double nerve.) Chitons.

Example — Chiton.

Class 2 — Gasteropoda. (Stomach foot.) Snails, whelks, slugs.

Examples — Helix, Limax, Natica, Busycon, Triton, Urosalpinx.

Class 3 — Pelecypoda. (Hatchet foot.) Oysters, clams, mussels, scallops.

Examples — Ostrea, Mya, Venus, Mactra, Tridacna, Unio, Lampsilis, Ensis, Pholas, Pecten, Anodonta, Teredo.

Class 4 — Cephalopoda. (Head-footed, *i.e.*, head with tentacles.) Squid, cuttle fish, devil fish or octopus.

Examples — Nautilus, Sepia, Loligo, Octopus.

Class 5 — Scaphopoda. (Boat foot.)

Example — Dentalium.

Phylum — Arthropoda. (Jointed foot.) About 430,000 species.

Class 1 — Crustacea. (Skin-crust.)

Examples — Daphnia (Water flea), Lepas (Gooseneck barnacle), Balanus (Rock barnacle), Oniscus (Sow bug), Gammarus (Fresh-water shrimp), Homarus (Lobster), Cambarus (Crayfish), Callinectes (Blue crab), Penaeus (Shrimp), Libinia (Spider crab).

Class 2 — Onycophora. (Claw bearing.)

Example — Peripatus.

Class 3 — Myriopoda. (Ten thousand feet.) Centipedes, millipedes.

Examples — Lithobius, Julus, Scutigera.

Class 4 — Insecta. (Cut into.)
  Order 1 — Coleoptera.
    Examples — Beetles, Weevils, June bugs.
  Order 2 — Hymenoptera.
    Examples — Ants, Bees, Wasps.
  Order 3 — Siphonaptera.
    Example — Fleas.
  Order 4 — Diptera.
    Examples — Flies and Mosquitos.
  Order 5 — Aptera.
    Example — Fishmoths.
  Order 6 — Ephemerida.
    Example — May-fly.
  Order 7 — Odonata.
    Example — Dragon-fly.
  Order 8 — Isoptera.
    Example — Termites or White Ants.
  Order 9 — Orthoptera.
    Examples — Cockroaches, Grasshoppers, Crickets.
  Order 10 — Hemiptera.
    Examples — Bugs, Lice, Locusts, Aphids, Scale Insects.
  Order 11 — Neuroptera.
    Example — Ant-lions.
  Order 12 — Lepidoptera.
    Examples — Butterflies and Moths.
  Order 13 — Thysanoptera.
    Example — Thrips.
  Order 14 — Dermaptera.
    Example — Earwigs.
  Order 15 — Corrodentia.
    Example — Book-lice.
  Order 16 — Mallophaga.
    Example — Bird-lice.
  Order 17 — Trichoptera.
    Example — Caddice-flies.
  Order 18 — Plecoptera.
    Example — Stone-flies.
  Order 19 — Mecoptera — Scorpion Flies.
Class 5 — Arachnida. (Spider.)
  Examples — Limulus (King-crab), Scorpion, Tarantula, Spiders, Ticks and Mites.

Phylum — Chordata. (Notochord.) About 30,000 species.
  Sub-phylum I — Prevertebrates.

- Class 1 — Hemichorda. (Enteropneusta.)
  - Example — Balanoglossus.
- Class 2 — Urochorda. (Tunicata.) Sea-squirts.
  - Examples — Molgula, Cynthia, Ciona, Salpa.
- Class 3 — Cephalochorda.
  - Example — Amphioxus, the lancelet.

Sub-phylum II — Vertebrata. (Craniata.)

- Class 1 — Cyclostomata. (Round mouth.) Lampreys and Hag Fish.
  - Examples — Petromyzon, Myxine, Bdellostoma.
- Class 2 — Pisces.
  - Sub-class I — Elasmobranchii.
    - Examples — Sharks, Skates, Sting-rays, Torpedo, Dogfish, Sawfish.
  - Sub-class II — Teleostomi.
    - Examples — Cod, Mackerel, Herring, Shad, Haddock, Swordfish, Tarpon, Trout, Salmon, Pickerel, Sucker, Eel, Seahorse, Goosefish, Gars, Bowfin, Sturgeon, Flounder, Whitefish, Tilefish.
  - Sub-class III — Dipnoi.
    - Examples — Neoceratodus — Australia.
      - Protopterus — Africa.
      - Lepidosiren — South America.
- Class 3 — Amphibia.
  - Order 1 — Apoda.
    - Example — Ichthyophis.
  - Order 2 — Caudata. (Urodela.)
    - Examples — Mud Puppy, Hellbender, Siren, Congo eel, Giant Salamander, Salamanders and Newts.
  - Order 3 — Salientia. (Anura.)
    - Examples — Frogs, Toads, Tree Frogs.
- Class 4 — Reptilia.
  - Order 1 — Rhyncocephalia.
    - Example — Sphenodon.
  - Order 2 — Lacertilia.
    - Example — Lizards.
  - Order 3 — Ophidia.
    - Example — Snakes (Serpents).
  - Order 4 — Chelonia.
    - Examples — Turtles and Tortoises.
  - Order 5 — Crocodilia.
    - Examples — Alligators, Crocodiles and Gavials.
- Class 5 — Aves.

- Sub-class 1 — Archaeornithes.
  - Example — Archaeopteryx. (Extinct.)
- Sub-class 2 — Neornithes.
  - Division 1 — Ratitae.
    - Example — Ostrich.
  - Division 2 — Carinatae.
    - Examples — Emu, Cassowary, Kiwi, Penguin, Albatross, Heron, Flamingo, Ducks, Geese, Terns, Gulls, Fowls, Pigeons, Parrots, Owls, Wrens, Sparrows, Crows.

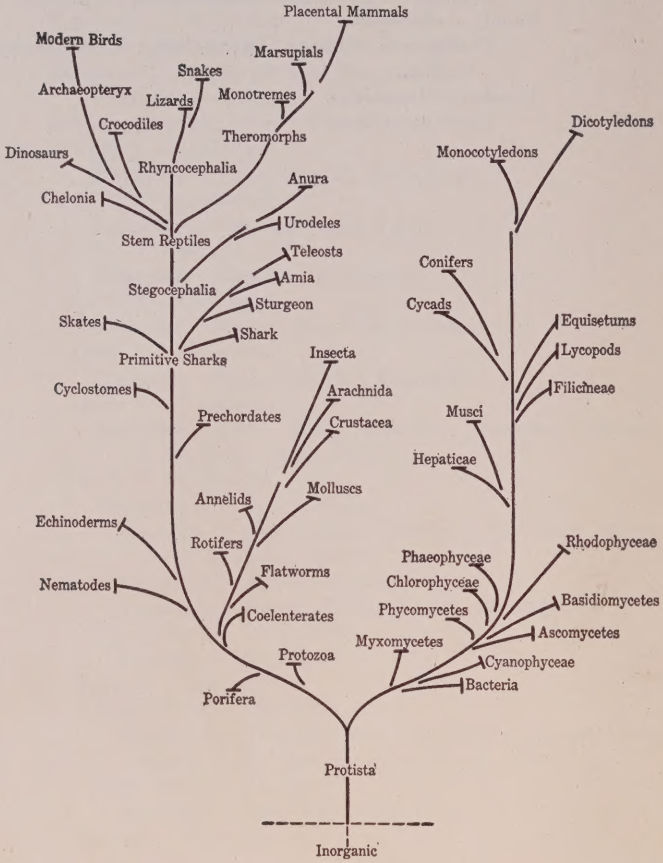
Class 6 — Mammalia.

- Sub-class 1 — Prototheria or Monotremata.
  - Examples — Spiny Anteater, Duckbill.
- Sub-class 2 — Metatheria or Marsupialia.
  - Examples — Kangaroo, Opossum, Wallaby.
- Sub-class 3 — Eutheria or Placentalia.
  - Order 1 — Insectivora.
    - Examples — Moles, Shrews, Hedgehogs.
  - Order 2 — Chiroptera.
    - Examples — Bats and Flying Foxes.
  - Order 3 — Sirenia.
    - Examples — Manatee and Dugong.
  - Order 4 — Cetacea.
    - Examples — Whales, Porpoises, Dolphins.
  - Order 5 — Edentata.
    - Examples — Sloth, Anteater, Armadillo.
  - Order 6 — Rodentia.
    - Examples — Mice, Rats, Rabbits, Squirrels, Beavers, Porcupines, Guinea Pigs.
  - Order 7 — Ungulata.
    - Sub-order 1 — Artiodactyla.
      - Examples — Pigs, Camels, Giraffes, Cattle, Deer, Hippopotamus, Bison, Moose.
    - Sub-order 2 — Perissodactyla.
      - Examples — Horses, Zebras, Tapirs, Rhinoceroses.
    - Sub-order 3 — Proboscidea.
      - Example — Elephants.
  - Order 8 — Carnivora.
    - Sub-order 1 — Fissipedia.
      - Examples — Dog, Cat, Fox, Lion, Tiger, Leopard, Lynx, Skunk, Wolf, Raccoon, Bear, Weasel, Otter.
    - Sub-order 2 — Pinnipedia.
      - Examples — Seal, Walrus, Sea Lion.
  - Order 9 — Primates.

Sub-order 1 — Lemuroidea.
  Family — Lemuridae.
    Example — Lemurs.
Sub-order 2 — Anthropoidea.
  Family — Hapalidae.
    Example — Marmosets.
  Family — Cebidae.
    Examples — Howling Monkeys, Spider Monkeys.
  Family — Cercopithecidae.
    Examples — Macaques and Baboons.
  Family — Simiidae.
    Examples — Gibbon, Orang-utan, Chimpanzee, Gorilla.
  Family — Hominidae.
    Example — Man.

APPENDIX B

A GENEALOGICAL TREE OF ORGANISMS


Placental Mammals
Modern Birds
Marsupials
Snakes
Archaeopteryx
Lizards
Monotremes
Crocodiles
Theromorphs
Dicotyledons
Dinosaurs
Monocotyledons
Rhyncocephalia
Anura
Chelonia
Urodeles
Stem Reptiles
Teleosts
Conifers
Amia
Stegocephalia
Cycads
Sturgeon
Equisetums
Skates
Shark
Lycopods
Insecta
Primitive Sharks
Filicineae
Cyclostomes
Arachnida
Musci
Prechordates
Crustacea
Hepaticae
Molluscs
Annelids
Echinoderms
Rotifers
Rhodophyceae
Phaeophyceae
Flatworms
Nematodes
Chlorophyceae
Basidiomycetes
Phycomycetes
Coelenterates
Ascomycetes
Myxomycetes
Protozoa
Cyanophyceae
Bacteria
Porifera
Protista
Inorganic

APPENDIX C

BIOGRAPHICAL CATALOGUE OF SOME MASTER BIOLOGISTS[1]

ippocrates (460–370 B.C.). Greek: "Father of Medicine." Applied the scientific method in treating disease.

ristotle (384–322 B.C.). Greek philosopher, investigator and teacher. Pupil of Plato. Teacher of Alexander the Great. Established the science of Natural History. Writings extensive, "History of Animals," etc. His writings looked upon as authoritative for centuries.

alen (A.D. 131–201). Greek, practiced medicine and taught anatomy at Rome. His "Anatomy" based on information derived from dissection of lower animals and so contained errors. Nevertheless it was taught for centuries.

esalius, Andreas (1515–1564). Belgian; studied at Louvain, Leyden, Paris. Professor of Surgery at Padua. Wrote first good textbook of human anatomy in 1543.

abricius, Hieronymus (1537–1619). Pupil of Fallopius at Padua. Later professor of Anatomy at Padua and taught William Harvey.

arvey, William (1578–1657). Graduate of Cambridge; M.D., Padua. Physician to King Charles I. Lecturer in Anatomy. Discoverer of the circulation of the blood, 1628. Studied embryology also. "Father of Modern Medicine."

edi, Francesco (1626–1698). Italian. Experiments in disproof of spontaneous generation.

alpighi, Marcello (1628–1694). Professor at Bologna. Indefatigable investigator. Anatomy of silkworm; Embryological studies; Anatomy of plants.

wammerdam, Jan (1637–1680). Dutch. Ardent investigator of minute forms. Devised method of injecting blood vessels, master of minute anatomy of insects.

ooke, Robert (1635–1703). English. Brilliant and versatile in physics, mathematics and natural history. First used the word "cell."

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[1] The chronological order is departed from at times. This list is by no means omplete.

Grew, Nehemiah (1628–1711). English botanist. His "Anatomy of Vegetables," the beginning of plant histology.

Ray, John (1628–1705). Worked in botany and zoology. The "Ray Society" of London named in honor of John Ray.

Leeuwenhoek, Antony van (1632–1723). Self-educated. Holland. Microscopic biology. Fellow Royal Society, London.

Haller, Albrecht von (1708–1777). Professor Botany, Anatomy and Medicine at Göttingen. Wrote "Elements of Physiology," 1757–1765.

Linnaeus, Carolus (1707–1778). Professor of Botany at Upsala. His "Systema Naturae" (10th ed. 1758), a comprehensive survey, a model taxonomy in which he introduced the binomial system of nomenclature. Opposed evolution.

Buffon, George, *Comte de* (1707–1778). French naturalist, Superintendent of Jardin du Roi. Author of "Histoire Naturelle." Probably believed in evolution.

Camper, Peter (1772–1789). Dutch. Anatomist. Made a number of discoveries in anatomy.

Hunter, John (1728–1793). Scotch. Surgeon. Established great anatomical museum in London.

Wolff, Caspar (1733–1794). Breslau and St. Petersburg. Author of "Theoria generationis," 1759, and "De formatione intestinorum," 1768–1769. Opposed preformation with his epigenesis theory of development.

Spallanzani, Lazarro (1729–1799). Professor at Modena and Pavia. Experiments in disproof of theory of spontaneous generation.

Darwin, Erasmus (1731–1802). Physician in England. Fellow Royal Society. Author of Zoonomia. Argued for evolution.

De Jussieu, A. L. (1748–1836). Botanist: Natural System of Classification; "Genera Plantarum."

Treviranus, Gottfried (1776–1837). Germany. One of the first to use word Biology, "Biologie, oder Philosophie der lebenden Natur," 1802.

Lamarck, Jean Baptiste de (1744–1829). French. Jardin des Plantes. Botany, zoology, evolution. "Philosophie zoologique," 1809.

Cuvier, Georges (1769–1832). Baron of France; protégé of Napoleon Bonaparte. Jardin des Plantes. Founder of comparative anatomy and palaeontology. Opposed idea of evolution.

Goethe, Johann Wolfgang von (1749–1832). Poet, philosopher and naturalist. "Versuch die Metamorphose der Pflanzen zu erklären," 1790. Evolutionist.

Saint-Hilaire, Geoffroy (1772–1844). Jardin des Plantes. "Philosophie Anatomique." 1818. Debated with Cuvier on evolution.

BAER, KARL ERNST VON (1792–1876). Professor at Königsberg and St. Petersburg. Founded Comparative Embryology.

MÜLLER, JOHANNES (1801–1858). Professor at Berlin. Comparative Physiology. A master intellect. "Handbuch der Physiologie des Menschen." Inspiring teacher.

SCHLEIDEN, MATTHIAS (1804–1881). Professor of Botany at Jena. Founder of Cell Theory with Schwann. "Ueber Phytogenesis," 1838.

SCHWANN, THEODOR (1810–1882). Professor of Anatomy at Liège. (See Schleiden.) "Mikroskopische Untersuchungen," 1839.

LIEBIG, JUSTUS VON (1803–1873). Chemist. Professor at Munich. "Organic Chemistry in Relation to Agriculture and Physiology," 1840.

LYELL, CHARLES (1797–1875). Geologist. "Principles of Geology," 1830–1833. This aided Darwin in developing his arguments for the theory of evolution.

SCHULTZE, MAX (1825–1874). Professor at Halle and Bonn. "Father of Biology," showing that protoplasm is similar in plants and animals.

DARWIN, CHARLES (1809–1882). Graduated from Cambridge University. Voyage of the *Beagle,* 1831–1836. "Origin of Species," 1859. "Descent of Man," 1871. Darwin established the Theory of Evolution.

HOOKER, JOSEPH (1817–1911). Contemporary of Darwin. Botanist. His "Flora of British India," appeared in 1872–1879.

MENDEL, GREGOR (1822–1884). Abbot of monastery at Brünn, Austria. Wrote "Versuch über Pflanzen-Hybriden," 1865. Founder of modern science of Genetics.

AGASSIZ, LOUIS (1807–1873). Professor of Geology and Zoology at Harvard. Founded Museum of Comparative Zoology at Harvard in 1859. Founded what is known now as the "Marine Biological Laboratory." A great teacher. Opposed to the theory of evolution.

BERNARD, CLAUDE (1813–1878). Experimental physiologist in Paris. Wrote a book on "Phenomena Common to the Life of Animals and Plants." Made a number of important discoveries in physiology.

WÖHLER, F. (1800–1882). Chemist. Synthesis of Urea. United organic and inorganic chemistry.

BALFOUR, F. M. (1851–1882). Embryology and evolution. "Treatise of Comparative Embryology."

MILNE-EDWARDS, HENRI (1800–1885). Professor at the Sorbonne. "Physiology and Comparative Anatomy," 1857–1880.

DUBOIS-REYMOND, EMIL (1818–1896). Succeeded Müller as Professor of Physiology at Berlin. Investigated animal electricity. Physico-chemical nature of life.

GRAY, ASA (1810–1888). Professor of Botany at Harvard. His "Manual of Botany" is a standard Plant Taxonomy.

LEIDY, JOSEPH (1823–1891). Professor of Anatomy at Pennsylvania.

"Fresh Water Rhizopods of North America," 1879. "Mammalian Remains in Nebraska," 1853.

Nägeli, Carl (1817–1891). Munich. Plant cytology. Abstract speculations.

Fol, H. (1845–1892). Geneva. Animal cytologist. Mitosis. First to see sperm enter an egg.

Owen, Richard (1804–1892). Professor of Anatomy at London. British Museum. Anatomy and physiology of the vertebrates. Fossil birds. Opposed idea of evolution. Analogy *vs.* homology.

Helmholtz, H. (1821–1894). Berlin. Physiological physics of nerves, eye and ear. Invented ophthalmoscope.

Pasteur, Louis (1822–1895). Professor of Chemistry at Strasburg, Lille, Sorbonne. Director, Pasteur Institute, Paris. Fermentation and Bacteriology.

Ludwig, Carl (1816–1895). Professor at Leipzig. Developed graphic method of recording physiological processes.

Huxley, Thomas Henry (1825–1895). Investigator in anatomy and palaeontology. Teacher, lecturer and great exponent of the theory of evolution.

Koelliker, Albrecht von (1817–1905). Professor at Würzberg, Embryologist and Histologist, "Handbuch der Gewebelehre," 1852–1893.

Cope, Edward Drinker (1840–1897). Professor at Pennsylvania. Palaeontologist with U. S. Geological Survey. "Origin of the Fittest," 1886.

Müller, Fritz (1821–1897). Author of "Fur Darwin." Elaborated Biogenenetic Law. Influenced Haeckel.

Sachs, Julius (1832–1897). Botanist. Made Würzburg world center for study of Botany. Experimental plant physiology.

Eimer, Th. (1843–1898). Orthogenesis — (Definitely directed evolution.)

Leuckart, K. (1822–1898). Morphology of invertebrates: Creator of several phyla.

Marsh, O. C. (1831–1899). Professor of Palaeontology at Yale. Collections of fossil horses, etc.

Zittell, Karl von (1839–1904). Professor at Munich. Author of standard textbook on Palaeontology.

Virchow, Rudolph (1821–1903). Professor at Berlin. Author of "Cellular Pathology," 1858.

Gegenbaur, Carl (1826–1903). Professor at Heidelberg. Comparative anatomy. "The ultimate aim of comparative anatomy is phylogeny."

Spencer, Herbert (1820–1903). Philosopher; Evolutionist: "System of Synthetic Philosophy."

His, Wilhelm (1831–1904). Leipzig. Physiology of embryology. Critic of biogenetic law.

Flemming, W. (1843–1905). Stages of Mitosis; Named *chromatin;* Protoplasm a network of fibers; His "pieces of chromatin" afterward named "chromosomes" by Waldeyer.

Koch, Robert (1843–1910). Professor at Berlin. Relation of Bacteria to disease. Isolation by gelatin culture.

Galton, Francis (1832–1911). Heredity and Eugenics. Cousin of Charles Darwin.

Strasburger, E. (1844–1912). Botanist. Jena and Bonn. Plant cytology.

Lister, (Lord) Joseph (1827–1912). English Surgeon. Antiseptic surgery.

Wallace, Alfred Russell (1822–1913). Naturalist. "Geographical Distribution of Animals," 1876. Contemporary of Darwin and arrived at a theory of evolution by natural selection at about the time Darwin was ready to publish "The Origin of Species."

Weismann, August (1834–1914). Professor of Zoology at Freiburg. Wrote the "Germ Plasm Theory," 1885. The development of the germ plasm idea focused attention on the chromosomes and laid the basis for work in genetics. Weismann strenuously opposed the inheritance of acquired characteristics.

Boveri, Th. (1862–1915). Cytologist. Centrosome is dynamic center of cell activities.

Ehrlich, Paul (1852–1915). Histology of leucocytes. Intravenous antisepsis; Serology.

Metchnikoff, E. (1845–1916). Director Pasteur Institute, Paris. Phagocytosis.

Fischer, Emil (1852–1919). Great chemist. German. Worked on synthesis of carbohydrates, on proteins, etc.

Haeckel, Ernst (1834–1919). Professor of Zoology at Jena. Author of "Generelle Morphologie," 1866. "Die Radiolarien," 1862. "History of Creation," 1911. An ardent evolutionist.

Loeb, Jacques (1859–1924). Physiologist. Professor at Bryn Mawr, Chicago, California, and Member of Rockefeller Institute for Medical Research in New York. Career devoted to explaining life phenomena in terms of physics and chemistry. Prolific and profoundly stimulating investigator.

Roux, Wm. (1850–1924). Selectionist. Phylogeny. Selection within the egg. Founder of experimental embryology.

Golgi, C. G. (1844–1926). Pavia. Neurologist. Devised "Golgi Method" of staining nerve cells.

Bateson, William (1861–1926). Distinguished British geneticist.

Author of "Materials for the Study of Variation" and "Mendel's Principles of Heredity."

Dean, Bashford (1867–1928). Paleo-Ichthyology. Established the "Bibliography of Fishes."

Noguchi, Hideyo (1878–1928). Rockefeller Institute, N. Y. Bacteriologist. "Yellow fever."

APPENDIX D

GLOSSARY

A

Acid Solution — One in which the H ions are in excess of the OH ions.

Adaptation — The process by which an organism becomes adjusted to its environment; the fitness of a particular part for a particular use; the state of being adjusted to the environment.

Adipose Tissue — A form of connective tissue, composed chiefly of cells filled with fat.

Adjustor — The neurons concerned in transferring a sensory impulse into a motor impulse.

Adrenal — An endocrine gland on or near the kidney.

Adrenalin — A hormone produced by the adrenal.

Aedes — A genus of mosquito. Transmits yellow fever organism.

Afferent Nerve — One that conducts (sensory) impulses from the periphery toward a nerve center.

Albumin — A compound protein. Found in white of egg.

Allantois — Sac formed by evagination from posterior floor of embryonic gut of Reptilia and higher Vertebrates.

Allelomorph — (Genetics.) A pair of contrasting or alternative unit characters inherited in Mendelian fashion.

Alkaline Solution — One in which the OH ions are in excess of the H ions.

Alternation of Generations. A life cycle in which a sexual form alternates with an asexual form.

Amino-acid — Amino derivatives of organic acids, in which one H ion is replaceable with an amino group, NH_2. Fischer called amino-acids the building stones of the proteins.

Amitosis — Direct cell division in which cells divide without organizing a mitotic apparatus.

Amnion — An embryonic sac formed in Reptiles, Birds and Mammals, filled with fluid and inclosing embryo.

Amoeboid — Having form and movement of an Amoeba.

Amphimixis — The mingling of two bodies of germ plasm in fertilization.

Anabolism — A general name for the constructive phases of metabolism.

Anaerobic — Refers to types of bacteria that live in absence of free oxygen.

Analogy — Similarity.

Anatomy — The science that deals with organ structure of living things.

Angiosperms — Sub-phylum of Spermatophyta in which inclosed (hidden) seeds are formed.

Anion — An ion that bears a negative charge of electricity.

Annelida — A phylum of worm-like animals with a segmented body. (Annulata or Annelids.)

Anopheles — A genus of mosquito that transmits malaria.

Annual — A plant that completes its life cycle in one season.

Antero-Posterior Differentiation — A form of body which has a front or head end and a tail or hinder end.

Anther — The outer end of a stamen where microspores (pollen) are produced.

Antheridium — A male sex organ in plants where microgametes (male gametes) are produced, as in Marchantia.

Anthoceros — A liverwort, unique in that the sporophyte is green.

Antibody — A substance formed in the blood which tends to render antigens harmless.

Antigen — A substance which, when introduced into the blood, will cause the formation of an antibody, which inactivates it.

Archaeopteryx — Fossil reptile-bird of the Jurassic Period. Had feathers and teeth. Claws on its digits.

Archegonium — Female sex organ in plants where megagametes (female gametes) are produced, as in Marchantia.

Archenteron — (Embryonic) Intestine of a gastrula. Primitive gut.

Artery — A blood vessel which carries blood away from the heart.

Arthropoda — A phylum of Invertebrates having segmented body and jointed appendages.

Artificial Parthenogenesis — Stimulation of eggs to develop by artificial agencies, not by sperm.

Artificial Selection — Production of desired qualities in domestic forms by repeated breeding of selected individuals.

Autosomes — (Genetics) Refers to all other chromosomes exclusive of sex chromosomes.

Autotomy — Refers to an operation carried on by some animals when they cast off an injured organ, as when a starfish drops an injured arm.

Autolysis — Self-digestion of an organ by enzymes produced by that organ. Under normal conditions such enzyme activity is prevented.

Axil — Angle between a leaf or branch and the stem.

Axon — That part of a neuron which conducts impulses away from the cell body or cyton.

B

Bacillus — A rod-shaped Bacterium.

Basic Metabolism — Those processes (chemical) concerned in *maintaining* the life of the cell or organism. (See functional metabolism.)

Bilateral Symmetry — A form of symmetry in which one half is similar to the other half.

Binomial Nomenclature — System devised by Linnaeus for naming species in which the form has two names, one for the genus and one for the species.

Biogenesis — The biologic law that, so far as we know, all organisms are derived from organisms; "All cells from cells." Opposed to theory of spontaneous generation.

Biogenetic Law — Law of recapitulation — that organisms in their development go through stages resembling ancestral forms of the group of which that animal is a member.

Biology — The science of living things, *i.e.*, organisms.

Blastopore — Opening to archenteron of a gastrula. Blastopore serves as mouth *and* anus.

Blastula — Embryonic stage in metazoan development — a sphere consisting of a single layer of cells inclosing a 'segmentation cavity.'

Botany — That branch of biology dealing with plants.

Brownian Movement — The vibratory movement of dispersed particles of a colloid.

Bud — An embryonic structure developing from the main body of an organism and which will form an organ or another individual.

Budding — Vegetative reproduction in animals by forming buds. In horticulture, a method of grafting.

C

Calyx — Outer set of floral envelope (Green). Composed of sepals.

Cambium — Meristematic tissue between xylem and phloem of a stem.

Capillaries — Fine network of thin-walled vessels in tissues, carrying blood to them.

Carboniferous — The latter part of the Paleozoic Era. Coal Age.

Carpel — A simple pistil or a part of a compound pistil of a flower.

Carpellate Cone — (Gymnosperms.) A cone (strobilus) composed of megasporophylls, which produce megaspores.

Cation — (Kation.) An ion that carries a positive charge of electricity.

Cell Membrane — The outer protoplasmic envelope of a cell.

Cell Theory — All organisms are single cells, or organizations of cells.

Cellulose — A carbohydrate substance forming the outer wall which incloses plant cells. Cotton fibers are almost pure cellulose.

Cenozoic — The latest geologic Era — the age of Mammals.

Central Apparatus — Consists of centrosome, centrosphere and astrosphere. Forms apparatus for mitosis. Centrosome not present in all cells.

Cerebellum — That part of vertebrate brain posterior to optic lobes and anterior to medulla.

Cerebrum — The anterior part of vertebrate brain. Cerebral hemispheres in man.

Chitin — Horny substance forming the exoskeleton of Insects and Crustacea.

Chlorophyll — In plant cells, the green coloring matter which can transfer energy of sunlight into chemical energy for carbohydrate synthesis.

Chloroplast — Small chlorophyll-containing plastids found within certain plant cells.

Chromatin — Unique nucleo-protein substance in the nucleus of cells, plays essential rôle in heredity.

Chromidia — Little masses sometimes found in cytoplasm, possibly chromatin discharged from nucleus.

Chromoplasts — Colored plastids in cytoplasm.

Chromosomes — Chromatin bodies of definite size, shape and number appearing at mitosis. All members of a given species have similar chromosomes.

Cilia — Microscopic hair-like cellular processes having a whip-like motion.

Cleavage — Early cell divisions in the developing egg.

Close or Self-Pollination — Transfer of pollen from stamens of a flower to stigma of the same flower.

Cnidoblast — Special ectoderm cell in such forms as Hydra, producing a nematocyst.

Cocci — Bacteria, spherical in shape.

Cochlea — That part of the inner ear which possesses the sensory cells, and other apparatus of hearing.

Coelenterates — A phylum of animals in which the body plan is essentially like that of a gastrula, *i.e.*, diploblastic, with ectoderm and endoderm.

Coelome — The true body cavity between intestine and body wall. Lined with derivatives of mesoderm.

Coenosarc — Central living core of hydroid 'stems,' composed of ectoderm and endoderm with a central cavity within endoderm.

Colloid — A state of matter in which very minute but ultramolecular particles remain in suspension in a fluid. Colloids are not easily crystallized, do not readily diffuse in solutions nor do they easily pass through membranes derived from organisms.

Commensalism — An association between two forms with no harm to either.

Complete Metamorphosis — A transformation in which an insect in its development has an egg, larva, pupa and imago (adult) stages.

Conceptacle — Cavity in receptacle of Fucus containing antheridia, oogonia or both.

Conifers — A subdivision of Gymnosperms, *i.e.*, pine, hemlock.

Conjugation. A form or reproduction in which two individuals come together and (*a*) as in Spirogyra, contents of one cell pass over and fuse with cell contents of other; or (*b*) as in Paramoecium, there is an exchange of nuclear material.

Continuous Phase — That phase of a colloid in which particles are dispersed (suspended). In smoke, air is the continuous phase and carbon (etc.) particles, the dispersed phase.

Contractile Vacuole — A vacuole forming in cytoplasm of many protozoa, probably filling with excretions, which are discharged when the vacuole contracts.

Copulation — Temporary conjugation of a male and female animal for transfer of sperm from male to female.

Corolla — Set of floral leaves or petals within the calyx.

Cranial Nerves — Those that originate from the brain.

Cranium — That part of skull inclosing the brain.

Crossing Over — In synapsis, chromosomes may twist around each other, so that in the reduction division there might be effected a new arrangement of linkage groups of genes.

Cross-Pollination — Transfer of pollen from one flower to pistil of another flower of the same species.

Cryptogam — Subdivision of plants including Thallophytes, Bryophytes and Pteridophytes.

Crystalloid — A substance composed of crystals which will completely dissolve and can be recovered in crystalline form.

Cupules — Small cups on dorsal surface of Marchantia thallus, which produce gemmae.

Cuticle — Outer limiting membrane of many animals. It is non-cellular. Example, cuticle of earthworm.

Cyst — A protective case or sac around a resting organism, although some cysts contain fluid (pathology).

Cytology — The science of cell morphology and physiology.

Cyton — The cell-body of a neuron, *i.e.*, that part containing the nucleus.

Cytoplasm — The protoplasm between the nucleus and cell membrane of a cell. Contrasted with nucleoplasm, the substance of the nucleus. The nucleus is a *body* and the word cytosome is used as meaning the *body* of the cell outside the nucleus.

Cysticerci — Bladder worms — asexual passive or encysted stage in the life cycle of the tapeworm.

D

Darwinism — See Natural Selection.

Dehydration Synthesis — A chemical process which involves the decomposition of molecules, the subsequent union of portions of them, resulting in formation of a new compound *with the loss of water*. Molecules of glucose and fructose unite forming cane sugar and water.

Dendrites — Short, stubby, irregular branching processes of a neuron which conduct impulses into the cyton.

Dialysis — Process by which a membrane permits diffusion of some substances in solution but withholds others.

Dicotyledon—An Angiosperm whose embryos have two seed leaves.

Diencephalon — Part of brain of Vertebrate between cerebrum and optic lobes. (The between brain.)

Diffusion — The distribution of particles of substances in solution as sugar in water; or when two liquids or gases are brought together.

Digestion — The process of changing complex compounds to a simpler form capable of being absorbed through cell membranes.

Dihybrid — A cross involving two pairs of alternative characters.

Dinosaurs — Great herbivorous and carnivorous reptiles of the Mesozoic Period.

Dioecious refers to organisms in which there are separate sexes, *i.e.*, males and females.

Diploblastic — Referring to animals whose tissues are derived from two germ layers, *i.e.*, ectoderm and endoderm, *i.e.*, Coelenterates.

Diploid — Paired condition of chromosomes and their contained genes in zygote cells, resulting from the contribution of one member of each pair from each parent.

Dipnoi — Lung-fish, which in water breathe by means of gills. In absence of water, their air bladder functions as a lung.

Disaccharid — A carbohydrate having the formula — $C_{12}H_{22}O_{11}$. Example: cane sugar.

Distal — Away from central axis of body.

Dominance — A Mendelian law according to which one member of an alternative pair of characters (which are both present in the same zygote) expresses itself over the other (recessive) member.

Dorso-Ventral Differentiation — A morphological relation in which there is a definite back or dorsal side, and a belly or ventral side.

Dura Mater — Tough connective tissue membrane inside skull and over the brain.

E

Echinodermata — Phylum of spiny-skinned animals with secondary radial symmetry.

Ecdysis — Shedding of exoskeleton by Arthropoda, or of skin by snake.

Ecology — Study of relation of organisms to their environment.

Ectoderm — Outer layer of cells of a gastrula.

Ectoplasm — Clear, non-granular layer of protoplasm at periphery of some cells.

Effector — The motor or muscular part of a reflex mechanism.

Efferent Nerve — A motor nerve which carries impulses from a center out to a muscle or gland.

Electrolyte — A substance which in solution breaks up into ions, having opposite electrical charges and thus becomes a conductor of an electric current.

Electron — Smallest particle of negative electricity; revolves about the nucleus of an atom.

Elephantiasis — Disease caused by Filaria, a nematode worm.

Embryo — The organism in its developmental stages. In higher Mammals, the well-advanced embryo is called a foetus.

Embryology — The science of the development of organisms.

Emulsoid — A colloid in which the dispersed and dispersing phases are liquid. Cream is droplets of fats dispersed in water. Most protoplasmic fluids are emulsoid.

Endocrine Gland — A ductless gland which secretes hormones into the blood stream.

Endoderm — Inner of two layers of cells of a gastrula.

Endomixis — Nuclear reorganization without conjugation, as in Paramoecium.

Endoplasm — (Endosarc.) Granular cytoplasm inside ectoplasm (ectosarc) of some cells.

Endosperm — Food tissue formed adjacent to embryo in embryo sac of some Spermatophytes.

Enteron — Gut or intestinal tract.

Enzymes — Protein-like compounds that hasten speed of organic chemical reactions.

Eohippus — The " dawn " horse of the Eocene Period of the Cenozoic Era.

Epicotyl — The portion of an embryo plant above the cotyledons. At upper tip is plumule, embryonic leaf bud.

Epidermis — Outer protective tissue of plants. Also outer part of skin of Vertebrates.

Epigenesis — Idea that embryos do not exist preformed in the egg, but that from generalized egg substance, a differentiated adult develops.

Epithelium — One of the main types of animal tissues, forms membranes which cover adjacent tissues.

Erythrocyte — Red blood cell, possesses hemoglobin.

Eugenics — A study of human heredity with a view toward discovery of principles, which, if applied, will improve the quality of the human race.

Euthenics — The study of environmental methods of improving the quality of the human race.

Evolution — In biology, the theory that plant and animal forms are constantly changing and that from time to time new races and species have been formed from preceding simpler and more generalized forms. Opposed to idea that all existing forms came into existence *all at once*, long ago.

Excretion — The process by which wastes of metabolism are eliminated from the cells and from the organism.

F

F_1 — The first filial generation, *i.e.*, the first generation produced in hybridizing or crossing parents of different varieties or species.

F_2 — The second filial generation produced by interbreeding members of the F_1 generation.

Factor — See ' gene.'

Fats — Compounds of fatty acids and glycerine.

Fauna — The animal life of a region.

Feces — Mostly undigested materials discharged from the anus of animals.

Female Gamete — Equivalent to egg cell or ovum or megagamete.

Female Gametophyte — A gametophyte that has only female sex organs.

Fertilization — A physiological process involving the union of a male and female gamete, *i.e.*, egg and sperm, forming a zygote.

Fibrin — Solid protein network formed from fibrinogen of the plasma when blood coagulates. It enmeshes the corpuscles.

Filterable Virus — Toxic material which passes through finest filters and causes disease, suggesting that it contains ultramicroscopic bacteria.

Fission — A form of reproduction in which the cell is divided into equal-sized daughter cells. Applied to single-celled organisms.

Flagellum — A whip-like motile appendage of certain cells. Larger than a cilium.

Flora — Plant life of a region.

Flower — That organ of an Angiosperm where microspores or megaspores or both are produced and where seeds may be formed.

Fossil — (Something that is dug up.) The petrified remains of a prehistoric organism.

Frond — The leaf of a fern, including stipe and blade.

Fruit — Seeds surrounded by ripened wall of ovary and sometimes by overlapping receptacle.

Functional Metabolism — Chemical processes having to do with the special work of a cell or organ, *i.e.*, over and above basic metabolism.

G

Gametangium — A structure producing gametes.

Gametes — Sex cells, which uniting produce a zygote.

Gametophyte — Sexual generation in plants which alternates with the asexual sporophyte.

Ganglion — A collection of nerve cells, forming a nerve center.

Gastrin — A stomach hormone causing gastric secretions.

Gastrula — An embryonic stage in metazoan development consisting of two germ layers, ectoderm and endoderm.

Gel — The solid state of a colloid.

Gene — A substance in the chromosome which is the determiner of specific hereditary qualities; supposedly an ultramicroscopic multimolecular body. The terms "Factor," "Unit character" and "Determiner" are less concrete.

Genetics — The study of the phenomena of inheritance according to which offspring are similar to and also different from their parents, and having in view the discovery of laws according to which characters are inherited.

Genotype — A group of individuals that have the same genic composition so far as certain specific characters are concerned.

Geographical Distribution — That branch of biology which seeks to explain the peculiarities of plant and animal distribution in different geographical areas.

Geotropism — Growth response of plants to the force of gravity.

Germination — Renewal of growth and development of embryos in seeds after a resting period following their formation.

Germ Layer — An embryonic group of cells from which similar adult tissues or organs will develop. The germ layers are ectoderm, mesoderm and endoderm.

Germ Layer Theory — Each embryonic germ layer develops into particular tissues in the triploblastic metazoa, *i.e.*, endoderm forms the lining of the gut; mesoderm, muscle tissue; ectoderm, skin and nerves, etc.

Germ Plasm — That protoplasm of which the germ cells (sperm and eggs) are composed.

Germ Theory of Disease — Certain types of disease are caused by Bacteria, *i.e.*, by microorganisms.

Gills — Organs of respiration in an aquatic organism. Spore-bearing tissue under cap of mushrooms.

Gill Slits — Slits or openings in wall of pharynx of fishes, provided with gills. (See tunicate and Amphioxus in text.) Also in embryos of higher Vertebrates.

Gland — An organization of cells whose function is secretion.

Glucose — A monosaccharid, $C_6H_{12}O_6$.

Glycogen — Animal starch, stored in liver.

Goiter — Enlarged thyroid gland correlated with deficiency of thyroxin.

Gonad — General name for reproductive glands of animals, *i.e.*, ovary or testis.

Gonangium — Reproductive member of a hydroid colony. Produces Medusae, asexually.

Grafting — Propagation of plants by special vegetative process. A portion of the plant to be propagated, known as the 'scion,' is *grown to* the 'stock' plant, which is commercially of little value. Seedless oranges can be propagated only in this way.

Growth — Involves increase in size of cells; formation of more cells; development of young cells into specialized mature tissues.

Gymnosperms — Sub-phylum of Seed Plants in which *exposed* seeds are formed.

H

Haemocyanin (Hemocyanin) — A protein-copper compound in arthropod blood, having an oxygen-transporting function.

Haploid — By oogenesis and spermatogenesis, the zygote pairs of chromosomes are separated so that each germ cell receives one chromosome of each pair of chromosomes possessed by the zygote cells. Paired genes are also segregated.

Haemoglobin (Hemoglobin) — The pigment in red blood cells which forms a temporary association with oxygen. A protein-iron compound.

Heart Wood — Centrally located xylem tissue, within the sap wood and no longer conducting soil water up the trunk.

Hermaphrodite — Organisms in which male and female sex organs are present in same individual. (Monoecious.)

Heterogametes — Dimorphic sex cells, *i.e.*, small microgametes and large megagametes.

Heterozygous — When the two members of a given factor pair, in the zygote chromosomes, are dissimilar genes, *i.e.*, alternative genes. Half the sex cells of that individual carry one of these genes and the other half carry the gene for the alternative character.

Hibernation — Refers to an animal remaining dormant during winter.

Hirudin — A substance obtained from glands of the leech, Hirudo. Prevents coagulation of blood.

Histology — Science of tissue construction of organs.

Holoblastic Cleavage — When entire egg undergoes cleavage, *i.e.*, equal in amphioxus and unequal in frog, etc.

Homoiothermic — Refers to warm-blooded animals in which a *constant* temperature is maintained.

Homolecithal — Even distribution of yolk in an egg.

Homology — Underlying similarity in structure indicating phylogenetic relationships.

Homozygous — When the two members of a given factor pair are similar genes, then the individual is homozygous for that character. *All* of its sex cells will carry the gene for that character.

Hook-Worm — A nematode parasite which causes hook-worm disease.

Hormone — A protoplasmic soluble substance which brings about integration of functions; a chemical messenger stimulating particular organs to function.

Hyaloplasm — Clear part of cytoplasm.

Hybrid — Offspring of parents belonging to different varieties or species. Theoretically it possesses pairs of alternative genes.

Hydranth — Hydra-like member of a hydroid colony.

Hydrogen-ion Concentration — The

proportion of H ions to OH ions in a solution.

Hydrolysis — A chemical reaction in which water is added to some compound and a new compound formed.

Hypha — A filament of a fungus plant body. The mass of hyphae form the mycelium.

Hypocotyl — Portion of the embryo plant below the cotyledons. Lower tip of hypocotyl is embryonic root.

I

Ichthyopsida — Fishes and Amphibia. Term used by Huxley.

Insulin — Hormone which controls metabolism of glucose (carbohydrate); elaborated by islands (of Langerhans) in pancreas.

Invertebrates — Animals without a backbone, *i.e.*, all forms except Vertebrates. Used by Lamarck, 1797.

Ion — Subdivision of an electrolyte. Ions bear positive or negative charges of electricity. *See* anion.

Irritability — Property possessed by protoplasm by which the equilibrium of the protoplasmic system is upset by a stimulus. This property belongs especially to sense cells.

Islands of Langerhans — Patches of endocrine tissue in pancreas which secrete the hormone, insulin.

Isogametes — Similar sized gametes, as in Ulothrix.

Isolation — A theory of Evolution: Restriction of animals in a sequestered region for a long time promotes development of new types.

K

Katabolism — A general name for destructive phases of metabolism.

L

Lamarckism — Theory of the inheritance of parental modifications or acquired characters as a cause of organic evolution.

Larva — Worm-like stage in development of insects; also stage in development of lower forms.

Larynx — Portion of trachea containing the voice box.

Law of Adaptive Radiation — Animals which are all members of a certain group become adapted to different environmental conditions and become accordingly specially modified so that diverse types result.

Law of Convergence of Form — Due to adaptation to same environmental medium, diverse animals have assumed similarity of form.

Leucocyte — (Leukocyte.) White blood cells.

Leucoplasts — Unpigmented bodies around which starch grains form in plant cells.

Lichen — A Thallophyte in which there is a symbiotic association between an Alga and a Fungus.

Linin — Fiber network in nucleus which supports chromatin particles.

Linkage — The theory that *inheritance together* of *groups of characters* is due to the *linkage* of a *series of genes* responsible for the characters and the transmission of these *linkage groups* to the zygote.

Liver-Fluke — Parasitic Trematode, in liver of sheep.

Lymph — Colorless fluid in tissue spaces and lymph vessels.

M

Malaria — Disease caused by a Sporozoan, Plasmodium.

Male Gamete — A sex cell which united with a female gamete produces a zygote. (Equivalent to microgamete or sperm cell.)

Male Gametophyte — A Gametophyte that has only male sex organs.

Mammary Gland — Between skin

and ventral body wall of mammals; secretes milk. A modified oil gland.

Marsupium — Pouch on abdominal wall of Metatheria.

Mechanistic Theory — Organic activities are due to the operation of the same physical and chemical forces as operate in the inorganic world.

Medulla — Posterior part of vertebrate brain, anterior to spinal cord.

Medusa — Free-swimming, sexual stage of certain Coelenterates.

Megagamete — A female or egg cell or large gamete which united with a microgamete forms a zygote, or fertilized egg.

Meganucleus — The larger, vegetative nucleus of Paramoecium.

Megaspore — A large spore that will develop into a female gametophyte.

Megasporophyll — A sporophyll that produces only megaspores.

Mendelism — The theory of inheritance based on principles discovered by Mendel.

Meristem — Plant tissue, the cells of which retain the power of cell division and growth as at the tip of roots and stems.

Mesoderm — Middle germ layer formed from endoderm or ectoderm.

Mesogloea — Jelly-like tissue between endoderm and ectoderm of coelenterates. Contains a few cells.

Mesonephros — Succeeds the pronephros and is functional kidney of fishes and amphibia but embryonic in higher vertebrates.

Mesophyll — Middle tissue of a leaf. Cells contain chlorophyll.

Metabolism — Totality of chemical processes that take place in living protoplasm.

Metanephros — Succeeds pronephros and mesonephros in developing Reptiles, Birds and Mammals in which it is the functional adult kidney.

Metagenesis — Alternation of a sexual with an asexual generation in the life cycle of such animals as Obelia.

Metamere — One of the segments of a metameric animal, as the worm.

Metamerism — A morphological characteristic, referring to the segmented condition of the body of Annelids, Arthropods and Vertebrates.

Metamorphosis — Change in form, as different forms assumed by a moth in its development, *i.e.*, egg, larva, pupa, imago; or by a frog which has a tadpole stage.

Metazoa — The many-celled animals in which there is more or less tissue differentiation.

Mesozoic — That geologic era between the Paleozoic and the most recent or Cenozoic. The great age of reptilian life.

Microgamete — A male sex cell, small gamete, sperm.

Micron — The thousandth part of a millimeter. $\frac{1}{24500}$ part of an inch.

Micronucleus — The smaller reproductive nucleus of Paramoecium.

Microspore — A small spore that will develop into a male gametophyte.

Microsporophyll — A sporophyll that produces only microspores.

Millimeter — The thousandth part of a meter, and the tenth part of a centimeter.

Mimicry — Similarity in external appearance of a defenseless form to an immune model.

Mitochondria — Discrete, permanent, spherical or linear masses in cytoplasm of many cells, lipoid in nature. Function problematical.

Mitosis — Division of cells involving elaborate division mechanism. An exact division of chromosomes is effected. Indirect cell division.

Mollusca — A phylum of soft-bodied invertebrate animals, having a muscular organ of locomotion called the *foot* and in most cases, a shell of calcium carbonate.

Monocotyledons — Angiosperms that have only one seed leaf.

Monoecious — Organisms in which male and female sex organs are present in the same individual.

Monosaccharid — Carbohydrate having the formula $C_6H_{12}O_6$, *e.g.* Glucose.

Morphology — The science that deals with the form and structure of organisms.

Morula — Late cleavage stage in metazoan development, consisting of a spherical mass of cells. Modified in many cases.

Mycelium — Plant body of a Fungus consisting of a mass of filaments.

Myogenic Theory — The basic rhythmical beat of the heart is due to an innate property of heart muscle and not to nerve impulses.

Myotomes — Segmentally repeated muscle masses of Amphioxus, fishes and embryos of higher Vertebrates.

Mutation — A different, discontinuous and permanent variation appearing in offspring of a parental line that did not possess it. In inheritance it is transmitted according to Mendelian principles.

N

Natural Selection — Darwin's theory that overcrowding, struggle for existence and survival of the fittest acted as a natural selection in the production of new species. Sometimes called Darwinism.

Nemathelminthes — A phylum of invertebrate animals; the round worms or Nematodes, worm-like with complete intestinal tract and a body cavity which is not a true coelome.

Nephridium — A kidney. The excretory tubule of the earthworm. Tubule of the vertebrate embryonic kidney.

Nephrostome — Internal opening or mouth of a nephridium.

Nerve Impulse — A progressive physico-chemical change passing along a nerve fiber.

Nitrogen-Fixing Bacteria (Bacillus leguminosum) — Have power of utilizing free nitrogen of atmosphere, making nitrogen compounds used by legume plants with which these bacteria are associated.

Notochord — A cellular rod extending lengthwise of the body above the intestine and under the nerve cord. Present in the Chordates. Embryonic in most Vertebrates.

Nucellus — Tissue immediately surrounding the megaspore in the ovule.

Nucleolus — Small body in the nucleus. Function problematical.

Nucleus (from Latin " kernel ") — A round or oval body within a cell, containing chromatin. The nucleus differs chemically from cytoplasm. It is the center of cellular activities and is essential to life of the cell.

O

" Omnis cellula a cellula " — Dictum of R. Virchow. All cells are derivatives of cells. Opposed to spontaneous generation theory. *See* ' Biogenesis.'

Ontogeny — Developmental history of an individual.

Oogenesis — Process of producing ova from ovary, involving reduction of chromosomes.

Oogonium — A simple female sex organ of plant, producing one or more ova as in Oedogonium and Fucus.

Operculum — A lid; covers gills of bony fishes, also internal gills of frog. See also operculum of Polytrichum spore case.

Orthogenesis — Evolution in a

straight line, determined by internal organization of germ plasm.

Osmosis — A process which occurs when a solution of a substance is separated from the solvent of that substance by a membrane permeable to the molecules of the solvent but impermeable to the molecules of the substance in solution. Molecules of the solvent pass back and forth through the membrane. Molecules of the substance are kept on the side of the membrane where they are in solution. In a given unit of time more molecules of the solvent will pass into the solution than will pass from the solution out through the membrane. This is due to a difference in diffusion pressure of the solvent in the two situations.

Osmotic Pressure — Osmotic pressure is the difference in diffusion pressure between (*a*) molecules of a solvent forming a solution with a substance and (*b*) the molecules of the pure solvent when they (*i.e.*, *a* and *b*) are separated by a membrane, permeable to the molecules of the solvent but impermeable to the molecules of the substance in solution. As a result of forming a solution, the pressure of the molecules of the solvent, per unit volume, are decreased as compared with the pressure of the molecules of the pure solvent outside the membrane and as a consequence more molecules of the pure solvent per unit of time will pass into the solution than will pass out. This will continue until equilibrium is attained. An osmometer, which measures osmotic pressure, is read at the time equilibrium is attained.

Oviducts — Ducts which convey eggs from ovaries.

Oviparous — Animals that produce eggs that develop outside the body of the female.

Ovum — An egg cell or female gamete.

Oxidation — A physiological process in which oxygen unites with a carbon compound such as glucose and effects a transfer of energy, utilized in metabolism.

P

Paedogenesis — Sexual reproduction in a larva.

Paleozoic — Era of geologic time, after the Proterozoic, when living forms first appeared in abundance, evidenced by fossils, mostly invertebrates. Great paucity of fossils in the Proterozoic and none in the preceding Archeozoic Era.

Pandorina — A spherical colony of cells which form an organism belonging to the Mastigophoran Protozoa. It resembles the morula embryo stage of some Metazoa.

Palaeontology — Science of organic life of past geologic ages.

Parthenogenesis — Development of ova without union with sperm cells, as in aphids.

Parasite — An organism that lives on, or in, or at the expense of another organism.

Parenchyma — A fundamental tissue of plants consisting of somewhat elongated, thin-walled cells. Acts as starch storage tissue in some cases.

Pathology — Study of changes in normal structure and functions brought about by disease.

Pectoral Girdle — The cartilages or bones which connect the anterior appendages of Vertebrates to the spinal column.

Pelvic Girdle — The cartilages or bones which connect the posterior appendages of Vertebrates to the spinal column.

Peripheral Nervous System — Refers to the cranial nerves and spinal nerves.

Penis — Male organ of copulation by which sperm are introduced into female genital receptacle.

Pepsinogen — A precursor of pepsin, a protein enzyme of the stomach.

Perianth — The calyx and corolla of a flower.

Perichondrium — The sheath of special connective tissue covering and nourishing cartilage. Chondriogenetic.

Periosteum — Sheath of special connective tissue which covers and nourishes bone. Osteogenetic.

Peripatus — A worm-like Arthropod, considered similar to probable ancestors of insects.

Peristalsis — A wave-like movement or succession of movements of tubes which have longitudinal and transverse muscle cells.

Peritoneum — Thin membrane lining body cavity. Derived from mesoderm.

Petal — Colored, leaf-like division of the corolla.

Pharynx — Portion of digestive tract between posterior part of oral cavity and the oesophagus. Gill slits of dogfish are in lateral walls of pharynx.

Phenotype — A group of individuals that have similar appearance but have different genetic constitutions.

Phloem — Tissue in plants which is used for conduction of sugar solutions.

Phylogeny — The evolution of a group of organisms, *i.e.*, the development of the race as opposed to ontogeny, the development of the individual.

Physiology — The science that deals with the functions of organisms.

Phanerogam — Spermatophyte, *i.e.*, plants which have flowers and seeds.

Photosynthesis — Process by which starch is made in the green leaf from carbon dioxide and water, when sunlight is present.

Pistil — A megaspore-producing organ of a flower; consists of outer stigma; middle style and lower ovary which contains ovules in which megaspores are produced.

Pituitary — Endocrine brain-gland, located ventral to the diencephalon.

Placenta — Embryonic and foetal structure in Eutherian Mammals, connecting foetus and mother for nutritive purposes.

Placoid Scale. — Tooth-like scale in skin of Elasmobranchs. Considered ancestral form of vertebrate teeth.

Plankton — Population of floating microorganisms of the ocean.

Plasma — Non-cellular, liquid part of blood which has not coagulated.

Plastids — Cytoplasmic bodies in cells, *e.g.*, chloroplasts.

Platyhelminthes — Phylum of invertebrate animals: Triploblastic; no coelome.

Poikilothermic — Refers to so-called cold-blooded animals in which body temperature varies with that of external medium.

Pollen Grain — Microspore of Spermatophytes.

Pollen Tube — Male gametophyte of Spermatophytes.

Pollination — Transfer of pollen from stamens to pistils. See kinds of.

Polysaccharid — A carbohydrate having formula $(C_6H_{10}O_5)_n$. Many combinations are possible. Examples: starch and cellulose.

Porifera — Phylum of Invertebrates — the sponges — pore-bearing.

Preformation — The idea that the embryo exists preformed in the egg, opposed to epigenesis.

Prelocalization — Some eggs exhibit evidences of localization of different tissue-forming substances.

Prenatal Influence — Idea that particular experiences during pregnancy will produce related effects in the offspring. Lacks scientific proof.

Procambial Strands — Elongated groups of procambium cells from which primary vascular bundles will develop in young roots and stems.

Proglottid — One of segments of a tapeworm.

Promeristem — Homogeneous tissue at tip of stem and root in which cell divisions take place in any plane.

Pronephros — Primitive embryonic kidney of Vertebrates.

Prophylaxis — Measures taken to prevent disease. Also to prevent spread of disease.

Protective Resemblance — When an organism resembles some part or feature of its environment so that it escapes notice, it is said to possess protective resemblance.

Protein — Compounds of amino-acids essential to life.

Prothallus — Small, flat, heart-shaped gametophyte of the fern.

Protista — Group of primitive (unicellular) organisms which are neither distinctly plant or animal. (Haeckel)

Proton — Smallest particle of positive electricity; the nucleus of an atom.

Protonema — A filamentous, branching, multicellular structure which develops from a moss spore. Buds on the protonema grow up into moss plants. It is part of gametophyte cycle.

Protophyta — Simple plant forms, unicellular or colonies of similar cells.

Protoplasm — The substance of which cells are composed and in which the processes of life occur.

Protozoa — Single-celled animals or animals that are colonies of similar cells.

Proximal — Toward central axis of body.

Pruning — Thinning out or cutting back the branches of a shrub or tree.

Pseudopodia — Irregular protoplasmic processes of locomotion in Sarcodina and other cells.

Pteridosperm — A seed-bearing fern-like plant of the Carboniferous Age. Considered ancestor of Cycads.

Pterodactyl — Flying reptile of the Mesozoic Era.

R

Receptor — General name for peripheral cell or sense organ which receives stimuli.

Recessive — A character which is not apparent when the gene of the alternative dominant character is present in the same zygote.

Reflex Action — Involuntary act caused by nerve impulses passing over a reflex mechanism. Name given by Descartes.

Regeneration — Repair of a cell from part of a cell; or of a tissue from a portion of it or of an organ from a part.

Respiration — Function concerned in delivering oxygen to cells and carrying away carbon dioxide.

Rhizoids — Hair-like extensions of under-epidermal cells, holding plant to earth and absorbing soil fluids. Found under Marchantia thallus and under prothallus of fern.

Rhizome — Underground root-like stem, as in Pteris.

Root Cap — Cap of cells at outer end of root tip.

Root Hair — Microscopic thin-walled outgrowths of root epidermis of higher plants, in contact with soil; the gateway of soil fluids into the plant.

Rudimentary Character — One that begins its development but remains immature.

Rhyncocephalia — Primitive lizard-like reptiles of New Zealand. Almost extinct.

S

Saprophyte — Plant that lives on dead organic matter.

Sap Wood — Peripheral region of xylem which transports soil water up the trunk.

Schizophyta — Fission plants, *i.e.*, Cyanophyceae and Bacteria.

Sclerenchyma — Strengthening tissue in plants; short, thick–walled cells.

Scolex — Head end of tapeworm.

Secretin — Duodenal hormone, activating pancreas to secrete.

Secretion — Process by which products elaborated by cells are discharged, also the product.

Seed — Embryonic plant with reserve food and protective coats.

Segregation — Mendelian principle. In germ-cell formation, alternative characters, associated in the zygote, are separated and each passes to a different germ cell.

Seminal Receptacles — Sacs in the earthworm which receive and store sperm received from another worm in copulation.

Seminal Vesicles — Sacs in the earthworm where are stored sperm produced by the testes of that worm.

Sepal — One of the divisions of the calyx.

Septa — Transverse partitions between intestine and body wall of a worm.

Sex-Linked Inheritance — Special case of linkage of some character with sex.

Sexual Reproduction — Involves union of male gamete and female gamete to form a zygote.

Smooth Muscle — Involuntary. Unit is a spindle-shaped uni-nucleated cell.

Sol — The liquid state of a colloid. Opposed to gel.

Somatoplasm — All of the body except germ plasm. Weismann's conception.

Somite — Segment of body of worm.

Sorus — Cluster of sporangia on under side of fertile frond of fern.

Spermatogenesis — Process of producing sperm from testis in which the diploid chromosomes of the zygote are reduced to the haploid number of the sex cell.

Spirillum — Bacterium — corkscrew in form.

Spongioplasm — More solid part of cytoplasm.

Sporangiophore — Stalk bearing a spore case as in Rhizopus.

Sporangium — Structure in which spores are produced. (Same as sporange.)

Spore — Reproductive cell which is asexual.

Sporophyll — Specialized leaf-like organ that bears sporangia.

Sporophyte — Asexual generation in plants; alternates with the sexual form or gametophyte.

Sporozoites — Spore-like stages in life cycle of Sporozoa.

Spring Wood — Large xylem cells formed in spring of year.

Staminate Cone — Composed of microsporophylls and producing pollen in Gymnosperms.

Statocysts — Organs of equilibrium in some Invertebrates.

Stele — Central vascular cylinder in woody stems.

Stoma — Air pore between two guard cells in epidermis of leaf.

Striated Muscle — Voluntary skeletal muscles. Unit is muscle fiber, an elongated, protoplasmic, striped, multinucleated cylinder.

Strobilus — Cone-shaped structure with a central axis, bearing sporophylls. In Pteridophytes and Gymnosperms.

Submicron — The thousandth part of a micron or millionth part of a millimeter.

Summer Wood — Small cells of xylem formed during later period of growing season.

Suspensoid — Colloid in which dispersed phase consists of solid particles.

Symbiosis — Living together of two forms with mutual benefit.

Sympathetic Nervous System — Two long, slender nerve trunks alongside backbone, possessing a series of ganglia and nerve connections to the central system and organs of the body. It is the *efferent* connection between central system and smooth muscle and glands.

Synapse — Junction by contact between peripheral end of one neuron and dendrites of another neuron.

Synapsis — Pairing of chromosome mates just before reduction divisions in spermatogenesis and oogenesis.

Syncytium — Mass of cells which have no separating cell membranes.

T

Tadpole — Fish-like larval stage of Amphibians.

Taxonomy — Science of classification of plants and animals.

Telegony — Idea that mating of a female with a certain type of male will affect the offspring of that female mated with another type of male. No scientific proof of it.

Telolecithal — Accumulation of yolk at one end of egg resulting in definite animal (active) pole where cell division is more frequent and an opposite vegetal (passive) end or yolk region as in the frog's egg.

Testis — Male sex gland which produces spermatozoa.

Texas Fever of Cattle — Disease caused by a Sporozoan. Intermediate host is the female tick.

Thallus — A simple plant body without stem, root or leaves.

Theory of the Gene — The characters of an organism are determined by the genes brought together at the time of fertilization of the egg. Includes all inheritance phenomena explained by the gene hypothesis.

Toadstool — Popular name for certain inedible and poisonous Basidiomycetes.

Trachea — Windpipe of land Vertebrates and air tube of insects.

Tracheid — Special type of xylem cell in plants. Long, thick-walled and tapering ends, with thickenings on inside, spiral or annular.

Transpiration — Plant function in which water vapor is dissipated from such organs as leaves.

Trichinosis — Disease caused by Trichinella, a Nematode.

Trichocysts — Spindle-shaped cavities in ectoplasm (of Paramoecium), explode and discharge threads for offense or defense.

Trihybrid — Cross between three pairs of alternative characters.

Trilobite — Primitive Arthropod found only in fossil state. Extinct since late Paleozoic.

Triploblastic — Refers to animals whose tissues develop from three primary germ layers.

Trochophore — Larval stage of some Annelids, resembling some adult Rotifers and larvae of some Flatworms and Mollusks.

Tropism — Response of an organism to modification of the environment, as phototropism and geotropism of plants and phototropism and chemotropism of Paramoecium or worm. From the Greek "to turn."

Trypanosome — A parasitic flagellate (Mastigophora) causing Sleeping Sickness disease. Intermediate host, tsetse fly.

Typhlosole — Projection of gland tissue along dorsal mid-line of earthworm intestine.

U

Urea — Waste product of protein metabolism $(NH_2)_2CO$.

Uterus — Posterior enlarged end of oviduct. Stores eggs temporarily in the frog. In the Primate it is the fusion of a portion of the posterior ends of both oviducts.

V

Variation — When members of a species resemble each other in species characteristics yet *differ* from each other in other characters. The differences are environmental or germinal.

Vasa Deferentia — Ducts which convey sperm from the testes.

Vasa Efferentia — Ducts which convey sperm from testis to kidney as in frog. In higher Vertebrates they are ducts within the testis.

Vascular Bundle — Small mass of conducting tissue in stems, consisting of a mass of xylem, cambium and phloem.

Vegetative Reproduction — A special form of asexual reproduction in plants. In horticulture plants are propagated by cuttings and by grafting.

Vein — Vascular tissue in the mesophyll of the leaf. Also a blood vessel in animals. A vein carries blood toward the heart.

Ventricle — A chamber in the vertebrate heart; also a cavity in the vertebrate brain.

Vertebrate — A Chordate with a backbone or spinal column composed of elements called vertebrae.

Vessel — In plants, a type of xylem cell.

Vestige — A persisting trace of an organ, once functional in an organism or in an ancestor of that organism.

Viscera — General name for organs of the body cavity.

Vitalism — Philosophical idea that activities of living organisms are directed by forces neither physical nor chemical, *i.e.*, ultra-scientific.

Vitamin — Organic accessory food substances which control normal metabolism.

Viviparous — Animals that bring forth living young. (*See* oviparous.)

Volvox — A colonial flagellate Protozoan resembling the blastula stage of higher metazoan embryos.

W

Wolffian Duct — The ureter of Amphibia. Serves as a sperm duct also. Homologous with sperm duct of Reptiles, Birds and Mammals.

X

Xylem — Soil-water conveying tissue of higher stems. In Dicotyledons it is inside cambium.

Z

Zone of Tissue Differentiation — Levels in young stems and roots, where adult tissues are forming.

Zoospores — Motile spores as in Ulothrix and Oedogonium.

Zygospore — Literally, a cell formed by the union of two spores. The gametes of Ulothrix uniting form a zygospore. The gametes resemble the zoospores although smaller and with two instead of four motile processes.

Zygote — Cell formed by union of two gametes (*i.e.*, male and female sex cells) and also the individual that develops from this fertilized egg.

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